# High-Stakes Aviation: U.S.-Japan Technology Linkages in Transport Aircraft

Committee on Japan
Office of Japan Affairs
Office of International Affairs
National Research Council

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Since 1985 the National Academy of Sciences and the National Academy of Engineering have engaged in a series of high-level discussions on advanced technology and the international environment with a counterpart group of Japanese scientists, engineers, and industrialists. One outcome of these discussions was a deepened understanding of the importance of promoting a more balanced two-way flow of people and information between the research and development systems in the two countries. Another result was a broader recognition of the need to address the science and technology policy issues increasingly central to a changing U.S.-Japan relationship. In 1987 the National Research Council, the operating arm of both the National Academy of Sciences and the National Academy of Engineering, authorized first-year funding for a new Office of Japan Affairs (OJA). This newest program element of the Office of International Affairs was formally established in the spring of 1988.

The primary objectives of OJA are to provide a resource to the Academy complex and the broader U.S. science and engineering communities for information on Japanese science and technology, to promote better working relationships between the technical communities in the two countries by developing a process of deepened dialogue on issues of mutual concern, and to address policy issues surrounding a changing U.S.-Japan science and technology relationship.

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# Executive Summary

## OVERVIEW

For more than 50 years, U.S. leadership in aircraft manufacturing and aviation has been a major component of our economic strength and national security. Today, that leadership is being challenged as U.S. aircraft primes[1] and a broad range of suppliers face depressed commercial markets, cuts in defense spending, and intense international competition. As markets, capital, and technological capabilities become increasingly global, international strategic alliances and other cross-border linkages have become a familiar feature of this industry. The importance of Japan and Japanese companies for the U.S. aircraft industry—as partners, customers, and competitors—is already substantial and growing rapidly.

It is in this environment of upheaval and opportunity that the National Research Council's Committee to Assess U.S.-Japan Technology Linkages in Transport Aircraft has examined the context, current status, and implications of U.S.-Japan relationships that develop or transfer aircraft technology. Although the European consortium Airbus Industrie is the only existing foreign prime for large commercial transports, this study of U.S.-Japan linkages is timely and appropriate for several reasons. To begin with, Japan's participation in the global aircraft industry is more extensive than is generally recognized, and has been achieved largely through alliances with U.S. industry. Further, the technological capability of Japan's aircraft industry is rising rapidly. If we look beyond the existing competition between primes to an industry constituted of sophisticated parts and subsystem suppliers, Japan's importance becomes more evident. Finally, other countries may seek to emulate Japan's strategies for aircraft industry development in the future. Therefore, a focus on U.S.-Japan relationships carries important implications for how overall competitive challenges will evolve in this industry.

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*From its assessment, the committee concludes that although co*
*and expanded U.S.-Japan cooperation is inevitable and consistent w*
*interests, a new approach is needed to ensure that this cooperation co*
*to reenergizing U.S. leadership in the aircraft industry.*

## MAJOR FINDINGS

1. *Leadership in global competition will increasingly go to the fi phasizing high-quality, low-cost manufacturing. This is precisely the c the Japanese have made their top priority—at the same time that the craft industry is making deep cuts in capital equipment investment.*

A major purpose of the assessment was to reexamine the widely sumption that Japan's aircraft industry is unlikely to move into the global leaders. During its study mission to Japan in June 1993, the co was impressed by the investments in state-of-the-art manufacturing eq made by the four "heavies" that lead Japan's aircraft industry—M Heavy Industries (MHI), Kawasaki Heavy Industries (KHI), Ishika Harima Heavy Industries (IHI), and Fuji Heavy Industries (FHI)—as w dedicated aircraft suppliers such as Teijin Seiki. Japanese industry has world-class capabilities in manufacturing aircraft components such as panels, thick and complex composite structures, long shafts for aircraft and primary actuation. Advanced technologies—including processes five-axis machines driven by design data bases—are combined with a lous approach to manufacturing practice to achieve high quality, low c reduced cycle time. In addition, the manufacturing excellence achi companies such as Toray in carbon fiber and Sharp in flat panel disp allowed Japanese industry to establish dominant positions in severa areas of the aircraft supplier chain.

Although some U.S. companies are making the investments nece stay on the cutting edge of manufacturing, many are not, largely as a ongoing cuts in military aircraft procurement and the current commerc ket slump. This is a critical issue because the forces shaping competit the next decade—growing but price-sensitive markets, industry restru and fewer brand-new aircraft and engine programs than in the past—m both U.S. primes and suppliers will be continually pressured to deliv value at lower cost.

2. *Japan's aircraft R&D and defense production systems actively f integrated and flexible dual-use technology and manufacturing base. trast, the commercial benefits of U.S. military aircraft R&D and proc have declined over time—largely as a result of policies that implicitly age military-commercial synergies.*

Although the amount of public resources expended on the Japanese industry is relatively small, Japan's government-sponsored domestic c tive programs are more strongly oriented to technology sharing

Japanese companies and commercialization of aircraft technologies than those supported by the U.S. government. For example, the Key Technology Center project on aluminum-lithium alloys launched in 1989 provides investment funding to aluminum manufacturers and fabricators for research likely to have important applications in the aircraft industry. In the United States, the National Aeronautics and Space Administration (NASA) aeronautics program has produced many advances that have enhanced the competitiveness of U.S. firms in the past, but there has been no comprehensive effort directed toward technology commercialization and product application technology.

Japanese and U.S. policies on the defense side provide contrasts as well. For example, Japan's defense R&D spending has a strong dual-use orientation, while U.S. military aircraft development increasingly emphasizes unique capabilities that enhance combat performance—such as stealth and high maneuverability—but have few direct commercial applications. In addition, the production facilities of Japanese companies often manufacture components for both military and commercial aircraft side by side or even on the same equipment, whereas U.S. companies such as McDonnell Douglas and Boeing have found it prudent to separate similar military and commercial manufacturing because of procurement regulations and unique military specifications. Although the current administration is initiating efforts to change such regulations, the existing system inherently separates (rather than integrates) military and civilian R&D and production.

3. *Japan uses international partnerships strategically to foster technology acquisition. Japan's policy and business environment allows industry to gain maximum leverage from international alliances, resulting in a gradual upgrading of independent technological capabilities and a diffusion of these skills throughout the manufacturing network of primes and suppliers.*

The Japanese aircraft industry does not carry out full independent integration of commercial airframes, engines, or avionics, but it has achieved increasing independence and growing technological strength by promoting international linkages. The Japanese government supported the JFR-710 project in the 1970s, laying the foundation for Japanese industry's participation in the multinational V2500 engine program. More recently, the Ministry of International Trade and Industry (MITI) launched the HYPR program in 1989, designed from the start as an international collaborative effort in advanced, supersonic engine technologies. The Japanese government has also supported and coordinated Japanese participation in Boeing's aircraft programs. MHI, KHI, and FHI have increased the extent and technical sophistication of their relationship with Boeing over time.

While the Japanese policy process for international partnerships is oriented toward "behind the scenes" advance government-industry coordination, the U.S. policy process is more ad hoc and uncoordinated. This contrast is particularly important now since both the U.S. and Japanese aircraft industries are

adjustments. International linkages are very much a focus of cur planning, as a series of new studies, working groups, and missions have been organized in past months to consider criti relevant to the future of the industry. MITI and industry are jointl new approaches to strengthen Japan's aircraft industry for the century. There is no such effort under way in the United States.

4. *The U.S. aircraft industry has gained significant benefits j tionships with Japan, including sales and licensing income, components, and financial leverage for costly new programs. Ye entails risks and raises concerns as well, particularly the long-ter technology transfer from the United States to Japan and the effec on the U.S. supplier base.*

Although the predominant flow of technology in U.S.-Japan ances has been from the United States to Japan, the U.S. D Defense (DOD) and U.S. companies involved in military and linkages have structured programs with the aim of protec technologies. Still, the impacts of the most recent technology unclear. Japanese industry is not competing today at the prime int but it already possesses or could acquire the capabilities needed addition, Japanese companies are displacing U.S. suppliers in a fuselage structures, and they dominate several critical component While Japan does not have offset requirements or other formal ma U.S. manufacturers selling to Japan feel informal pressure to so order to enhance access to Japanese airlines, and some have found participate in the Japanese market without a joint venture wit company.

*Rather than retreat into a "protectionist" or defensive stanc States should pursue a proactive approach to building effectiv relationships that involve a more balanced flow of aircraft tech tween the two countries. Further, there is a need to promote m working relationships between U.S. companies and between indu ernment to ensure the retention of an innovative, full-spectrum a pability in the United States.*

## IMPERATIVES FOR THE FUTURE

Although this study focuses on Japan, it is clear that U.S. le been and will continue to be challenged by other industrialized c view aviation as fundamental to their economic growth. The com oped future scenarios for the course of the global aircraft indust Japan alliances over the next decade and beyond. Several scenar template declining U.S. market share are plausible and could c current trends continue. *The most desirable scenario—a resurg*

*competitive U.S. aircraft industry—will not be realized unless U.S. companies and government work together to bring about a significant change in course.*

Leadership in aircraft design and manufacturing—including a full-spectrum supply chain—remains a vital U.S. national interest. As a result of its assessment, the committee concludes that in order for the United States to maintain its leadership in this critically important industry, government-industry partnering in the development and implementation of a long-term strategy is essential. While the major responsibility lies with the U.S. aircraft industry itself, government must do more to create a favorable overall environment. Currently, neither a coherent policy nor the needed institutional mechanisms exist.

## POLICY RECOMMENDATIONS

In response to the need for a comprehensive and proactive U.S. approach, the committee has developed a five-part strategy outlining the critical imperatives for U.S. industry and government attention, along with specific action items.[2] The five elements are

1. maintaining U.S. technological leadership,
2. revitalizing U.S. manufacturing capabilities,
3. encouraging mutually beneficial interaction with Japan,
4. ensuring a level playing field for international competition, and
5. developing a shared U.S. vision.

### Maintaining U.S. Technological Leadership

The current massive restructuring on both the military and the commercial sides of the aircraft business makes it critical that U.S. technological leadership be maintained. NASA must continue to play a key role in aeronautics. Its currently proposed 35 percent increase in aeronautics funding should continue for three more years. NASA's traditional role in basic research should be expanded into product-applicable technologies in subsonic aeronautics and propulsion systems, with the primary objective of reducing the investment and operating costs of future aircraft systems. To ensure increasing commercial application of these technologies, NASA should increase significantly the funding share contracted to industry. Also, the U.S. Department of Defense should maintain its aircraft R&D budget for enabling technologies at current levels despite overall cuts in the defense budget.

U.S. industry must continue to invest its own resources in new technology development. In order to facilitate this investment, the R&D tax credit should

[2]An abridged set of recommendations is presented here. The complete list is contained in Chapter 5.

be made permanent, and incentives should be developed to
companies that reorient their R&D from defense-unique to c
mercial areas.

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## Revitalizing U.S. Manufacturing Capabilitie

U.S. primes and suppliers will have to improve manufa
ance continually in terms of cost, quality, and delivery to rema
especially in view of the large investments in state-of-the-art
made by the Japanese aircraft industry. To this end, a well-s
ment tax incentive designed to encourage productivity-enhanc
should seriously be studied, both for its practicality and effectiv
pared to the incentives provided to industry in Japan and Europ

Department of Defense reform of its procurement system i
moting greater civil-military integration, especially in the area
riers to common R&D and manufacturing facilities for milit
aircraft production. Reform of the system should include more
commercial item descriptions, a greater emphasis on low cost a
and revisions in accounting standards. R&D funding by DOD
high priority on manufacturing and design processes, and give
eration between primes and suppliers in U.S. government RF
Proposals). DOD should also consider carrying aircraft
prototypes forward to limited production in order to demo
"manufacturability" as well as performance.

## Encouraging Mutually Beneficial Interaction with J

The environment surrounding U.S.-Japan linkages has e
cantly, demanding a new approach to ensure that the benefits of
maximized and the risks are managed. As part of its activit
greater reciprocity in the transfer of aircraft technology betw
States and international partners—including Japan—a privat
should be launched to identify critical technologies, establish gu
ing the transfer of commercial aerospace technology, and peri
international technology transfers. The Department of Comme
consider leading a new initiative to collect and disseminate
business information from global sources to the U.S. air
including expanded technology benchmarking.

## Ensuring a Level Playing Field for International Competition

In light of heightened international competition in all segme
craft industry and the context of heavy government involveme

policy should aggressively promote fair global market competition. The U.S. government should work closely with industry and other governments to achieve multilateral rules that govern and reduce subsidies in this industry. The recently increased Export-Import Bank guarantee and loan activity should also be maintained.

## Developing a Shared U.S. Vision

The four previous strategic elements and their associated recommendations are important ingredients for a reenergized U.S. aviation industry with enduring global leadership. What continues to be missing is an institutional mechanism that is committed to the further development and refining of a U.S. aviation strategy, that can understand and include the views of all the necessary players, and that has the visibility and persuasive powers to champion implementation. There is no present government agency that has singular responsibility for the aviation infrastructure. There is no U.S. equivalent of MITI, nor should there be. In any event, it is the private sector that is ultimately responsible for the success or failure of any aviation strategy.

The committee explored several alternative mechanisms for developing a shared vision, such as organizational changes in government, utilization of an existing advisory panel, or tasking one or more industry associations, and found all of these approaches wanting. Accordingly, its final recommendation is the establishment of a National Aviation Advisory Committee (NAAC), composed of knowledgeable leaders from industry, academia, and elsewhere, reporting to the National Economic Council or an interagency group of senior officials. The committee believes that the stature of its membership coupled with its strategic reporting level would help ensure knowledgeable input from the private sector to government councils, as well as a higher likelihood of a coordinated approach for an industry where the United States needs to retain world leadership. The committee recognizes that such a recommendation might be viewed as self-serving for a particular industry, and is aware of problems and mixed effectiveness of similar high-level advisory committees for other sectors. Nevertheless, during this period of restructuring following the ending of the Cold War and with increasing frictions in high-technology competition between the United States, Japan, and Europe, the committee believes that maintaining U.S. leadership in the aviation industry requires a careful assessment and a focused strategy from both U.S. industry and government. This report outlines some of the specific tasks that need to be accomplished. The NAAC as outlined here could perform these tasks as well as address the overriding need for a shared U.S. strategic vision for a continually reenergized leadership position in aviation.

# 1

# Introduction

The strong position that the U.S. aviation industry holds in the
represents one of America's great industrial success stories. The U.
industry, a major exporter, supplies more than half of the world
ranks sixth among U.S. industries in total sales. (See Appendi
analysis of the importance of the U.S. aircraft industry.) Many of
tencies built in this R&D-intensive industry diffuse to other industr
tribute to the overall economy.

The industry is in a real sense a major national asset. The U.S
position in aircraft is the result of a continuous stream of investm
technologies across a broad spectrum. Substantial support has com
ernment-funded projects that have spun off commercial applicatio
engine formed the core for the Pratt & Whitney JT8D engine on th
core of the GE F110 engine for the F-16 was used as a basis for dev
the CFM56 engine for the 737, A320, A321, and A340. Comme
are tested in National Aeronautics and Space Administration (N
tunnels, and NASA's work in areas such as computational flu
helped Boeing locate the nacelles on the wings of the 737, 757,
minimize drag.[1] At the same time, technology employed in
transports is often used in military programs, and commercial airc

[1]See U.S. Congress, Office of Technology Assessment (OTA), *Competing Econo
Europe and the Pacific Rim* (Washington, D.C.: U.S. Government Printing Office, 199

tion increasingly contributes to maintaining the supplier and work skill base, and produces cost economies for companies that manufacture both civilian and military aircraft.

The critical questions for this study are whether the United States can maintain its lead in the future, and the likely impacts of U.S.-Japan technology transfer and engineering relationships, broadly defined as technology linkages.[2] Japan's aircraft industry has generally been assumed unlikely to move into the ranks of the global leaders. A major purpose of this study, carried out by a committee of individuals with considerable experience in the industry and knowledge of Japan, was to reexamine that assumption and to look ahead to the future. The third in a series of studies on technology linkages organized by the National Research Council's Committee on Japan, this study, which included a committee study trip to Japan, was carried out during 1993 with support from the Defense and Commerce Departments and from the Japan-United States Friendship Commission.

A number of important contextual changes suggest that the future will be different from the past. Global competition is intensifying. Airbus rapidly increased its sales in Japan in 1991 and 1992, overtaking McDonnell Douglas.[3] Industry experts predict that Asia will play a major role in global demand in the 1990s and the first decade of the next century.[4] Over the next decade, or until new technology developments permit the introduction of supersonic and hypersonic transport aircraft, the committee believes that *leadership in global competition will increasingly go to the firms emphasizing high-quality, low-cost manufacturing. This is precisely the area that the Japanese have made their top priority.*

A major transformation is occurring in the industry as defense spending declines with the end of the Cold War. In the past, U.S. defense procurement drove R&D and capital spending in important segments of the industry and aircraft-related technologies. Today, the U.S. aircraft industry is struggling to adjust to these historic changes in a difficult context—a downturn in demand for commercial transports during the past few years. In Japan, where the U.S.-Japan alliance has formed the cornerstone of Japan's defense policy, declines in military procurement are also beginning to force hard choices.[5] President

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[2]Technology linkages include company-to-company activities (sales and maintenance agreements, licensed production, joint production or development, equity arrangements), as well as relationships involving governments and universities. See National Research Council, *U.S.-Japan Technology Linkages in Biotechnology* and *U.S.-Japan Strategic Alliances in the Semiconductor Industry* (Washington, D.C.: National Academy Press, 1992), for a detailed discussion of the term and approaches to analysis.

[3]These data were provided by GE Aircraft Engines. Airbus has sold to Japan Air Systems, a relatively new domestic airline. Japan Airlines (JAL) and All Nippon Airways (ANA) generally continue to purchase Boeing airplanes.

[4]Boeing Commercial Airplane Group, *1993 Current Market Outlook*, March 1993, p. 3.5.

[5]Japan Defense Agency (JDA) officials emphasized this point in discussions with the committee

Clinton has made it clear that the United States will maintain its military ence in Asia, at the same time working with Japan to build new multila approaches to security in the region. However, this is a time of political ch in Japan accompanied by a reexamination of fundamental principles. Thi mate of change and uncertainty is the larger context within which the transport aircraft industry must compete and cooperate with Japan.[6]

Although this study is primarily concerned with Japan, it is clear that leadership has been and will continue to be challenged by other industria countries that view aviation as fundamental to their economic growth. report contains frequent references and comparisons to Europe and other of the world. The central issues dealt with in this study are generic ones— are the benefits and what are the risks associated with expanding technolo linkages? The committee begins with the premise, well substantiated by p ous National Research Council (NRC) studies, that international technolo linkages are a fact of life. In the aircraft industry the primary U.S. partici are private companies who seek investment partners, entry to markets, rel suppliers with world-class manufacturing, and cooperators in new techno development. Japan is the world's second largest country market for airc most of them purchased from U.S. firms.[7]

Although the committee did not study linkages with other countries i same depth as those with Japan, overall the linkages and alliances that the aircraft industry undertakes with Japan are more significant—in both bus and technological terms—than linkages with any other single country.[8] O commercial side, for example, the links that U.S. airframe manufacturers with industries in China and Italy do not involve the extensive design coll ration that exists in Boeing's Japanese alliances. On the military side, Jap still the only ally that has been allowed to produce the McDonnell Dougl 15 under license, and most experts agree that the extensive interaction technology flow contemplated in the FS-X program go far beyond what been attempted in collaborative programs with other countries.

A major motivation for U.S. linkages with Japanese firms—market le age—is analogous to the motivation driving military offset deals conclude

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Japanese Diet approved a plan drafted by the Japanese Ministry of Finance that will limit incre JDA's budget for FY 1994 to about 1.9 percent (about $818 million) over the FY 1993 budget c billion. See Barbara Wanner, "Defense White Paper Stresses Regional Threats," *JEI Report*, No. August 20, 1993, p. 3.

[6]In June of 1993, the *Nihon Keizai Shimbun* reported that Kawasaki Heavy Industries had a to provide British Aerospace with advanced production control techniques for application to a n production facility. See "Kawaju no Kanri Gijustu Donyu" (Introducing KHI's Manag Technology), *Nihon Keizai Shimbun*, June 8, 1993, p. 1.

[7]The cumulative total of deliveries of jet airplanes to Japan through 1992 was $32.6 billion Boeing providing the bulk of them (data provided by Boeing).

[8]The significance of U.S.-Japan linkages varies across segments in relative terms. For exa although U.S.-Japan alliances are extensive and important in aircraft engines, the CFM Interna joint venture between General Electric and Snecma of France is clearly the most significant interna link by U.S. industry in this segment of the industry.

U.S. aircraft companies, and in some cases joint ventures involving companies from other countries. However, the available evidence indicates that no other country has achieved the level of success that Japan has thus far in leveraging international alliances to build and sustain a domestic aircraft industry.[9] This is because Japan's significance as a market and strategic partner has given it more leverage, and because the Japanese aircraft industry—working closely with the Japanese government—has taken better advantage of the opportunities afforded by alliances. From the Japanese perspective, a significant share of overall aircraft industry sales is derived from projects involving a U.S. linkage.[10]

Perhaps the main concern is that these linkages will, however, result in the building of strong commercial competitors by expanded transfer of U.S. technology abroad. Although normally framed in terms of the potential emergence of new airframe integrators, the downside risks affect even more directly the U.S. suppliers of subsystems and components, some subsegments of which are already losing market share to foreign firms. The U.S. aircraft industry, broadly defined to include the networks of related technical expertise and manufacturing capabilities that link the primary manufacturers and the suppliers, is a major national asset. The focus of this report is Japan—as a partner in both cooperation and competition—but the questions are generic, and it is hoped that the answers will contribute to building effective national policy, public and private, for the twenty-first century.

The chapters that follow provide a summary of the committee's analysis and recommendations. Chapter 2 provides a brief introduction to the historical evolution of Japan's aircraft industry and the overall policy context in Japan and the United States. Chapter 3 analyzes U.S.-Japan technology linkages in transport aircraft and draws conclusions about impacts on the United States. Chapter 4 outlines alternative scenarios for the future. Chapters 5 outlines policy issues and recommendations. Readers are encouraged to refer to the appendixes of this report for detailed information and assessment.

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[9]The members of Airbus Industrie have, of course, taken a very different path. They have leveraged their existing domestic capabilities in pursuing global market share through a multinational alliance.

[10]Between 1987 and 1991, Japan's aerospace exports to the United States more than doubled. See Aerospace Industries Association, *Aerospace Facts and Figures 1992-1993* (Washington, D.C.: AIA, 1992), p. 122.

# 2

# Background and Policy Context

## HISTORICAL BACKGROUND

Aircraft development has always been a high-risk, demanding busine Historically, new product development costs have often exceeded the mar value of the company making the investment. Currently, development costs a major new program (such as the Boeing 777) may exceed $5 billion.[1] T economics of the aircraft industry push toward international linkages formed share risk.

Powerful counterforces, however, explain the desire for an indigenous a craft industry in many nations where entry into the airframe integration s ment of the industry is economically irrational from the perspective of a individual company. Throughout the history of the Japanese aircraft indus there has been an interplay between the push for indigenously developed te nologies by an independent Japanese industry, and the need to form technolo linkages, given the realities of the global marketplace and the need to acc technology from abroad.

The four Japanese "heavies"—Mitsubishi Heavy Industries (MHI), Kav saki Heavy Industries (KHI), Fuji Heavy Industries (FHI), and Ishikawajin Harima Heavy Industries (IHI)—that dominate Japan's aircraft industry too have all been involved in aircraft production since the early part of the twe

**TABLE 2-1** Selected Japanese Aerospace Manufacturers
(Estimated FY 1992 million dollars, ¥110 per dollar)

| Company | Sales | Aerospace Sales (% of total) | Corporate R&D |
|---|---|---|---|
| MHI | 22,545 | 3,382 (15%) | 1,064 |
| KHI | 8,636 | 2,245 (26%) | 209 |
| IHI | 7,272 | 1,236 (17%) | 340 |
| FHI | 7,909 | 474 (6%) | 227 |
| Four Heavies, total | 46,362 | 7,337 (16%) | 1,840 |
| Toray | 5,409 | ? | 291 |
| Shimadzu | 1,569 | 439 (28%) | 118 |
| Teijin Seiki | 623 | 224 (36%) | 19 |
| JAE | 564 | 118 (21%) | 26 |
| Nippi | 300 | 288 (96%) | 3.6 |
| Selected suppliers total | 8,465 | ? | 458 |

NOTE: Companies do not provide breakout figures for aerospace or aircraft-related R&D.

SOURCE: Compiled by Office of Japan Affairs from data appearing in Toyo Keizai, *Japan Company Handbook—First Section* (Tokyo: Toyo Keizai, 1993).

eth century. Today they manufacture structural parts of aircraft and act as risk-sharing partners for large aircraft and engine development projects led in most cases by foreign-based firms (see Table 2-1). In addition to the four heavy industry companies that lead Japanese participation in commercial programs and act as prime contractors for major weapons systems purchased by the Japan Defense Agency (JDA), the Japanese aircraft industry consists of many subcontractors as well as many companies that have developed competitive capabilities in the manufacture of various aircraft components. In a number of cases, these companies, such as Toray, are applying technologies developed for another market segment. The United States has become increasingly dependent on Japanese suppliers for some types of components, such as flat panel displays. A distinguishing feature of the Japanese industry is its strength in components supply.

Japan's aircraft industry is also distinguished by its reliance on military production (see Table 2-2).[2] *In 1991, defense production accounted for almost 75 percent of Japan's total aircraft industrial output.*[3] At the same time, it is

[2]For FY 1992, JDA aircraft procurement was $2.46 billion (¥270 billion at ¥110/$1) versus U.S. Department of Defense aircraft procurement of $23.95 billion (estimated). See Boeicho (JDA), *Heisei Yonendo Boeihakusho* (Tokyo: Okurasho Insatsu Kyoku, 1992), p. 302; and Aerospace Industries Association (AIA), *Aerospace Facts and Figures 1992-1993* (Washington, D.C.: AIA, 1992), p. 22.

**TABLE 2-2** U.S. and Japanese Aircraft Industries—1991 Sales and Trade Compa
(million dollars, ¥110 per dollar)

| | United States | Japan |
|---|---|---|
| Total aircraft sales | 68,593 | 7,735 |
| Sales to domestic government[a] (% of total) | 21,703 (32%) | 5,926 (77%) |
| Aircraft imports | 12,626 | 5,127 |
| Aircraft exports | 42,412 | 841 |
| Aircraft trade balance | 29,786 | -4,286 |

NOTE: [a]For both countries, nearly all domestic government sales are military.

SOURCE: Nihon Kokuchukogyokai (Society of Japanese Aerospace Companies), *Heisei Yone* *Kokuchukogyo Nenkan* (Aerospace Industry Yearbook 1992 Edition), (Tokyo: Koku Nyusu, pp. 433-437; and Aerospace Industries Association, *Aerospace Facts and Figures 199* (Washington, D.C.: AIA, 1992), pp. 28, 126.

important to note that the same major Japanese companies that produce ai engage in widely diversified production of ships, nonaircraft military ve and engines, and missiles, as well as nonaerospace production in areas su motorcycles, electronic devices, and textiles. Industrial diversity is a hall of the large companies, a characteristic that enhances synergies between tary and civilian production that are unusual in the United States and exp encouraged by Japanese government policies.

Japan's pre-World War II industry was promoted for national pur and organized to acquire needed foreign technologies through licensin other linkages to foreign companies while at the same time building do Japanese capabilities through government-directed procurement, R&D planning.[4] Japan's success with the Mitsubishi A6M5, popularly known Zero fighter, demonstrated the high level of domestic capabilities spawn the "independent aircraft policy" of the 1930s.

Japan's aircraft industry, which had been one of the largest and most nologically advanced in the world during World War II, was initially proh production by the American occupation after the war. In the early postw riod, the industry was formally dismantled, and some of its accumulated te cal and human expertise flowed to other Japanese industries such as au

[4]For a detailed analysis, see Richard J. Samuels, chapter 4, "The Japanese Imperial Industry," *Rich Nation, Strong Army: National Security, Ideology, and the Transformation o* (Ithaca, N.Y.: Cornell University Press, forthcoming 1994).

biles.[5] The revival and expansion of the industry were made possible under the U.S.-Japan security treaty and were given their first stimulus during the Korean War when the U.S. military contracted with Japanese firms for significant maintenance and repair work.

The major mechanism for expansion of the military aircraft industry was licensed production in Japan of U.S.-designed aircraft, despite the considerably higher costs of production versus purchase of U.S.-made aircraft. Over time, Japanese firms progressed in defense production from assembly of U.S.-fabricated "kits" to production of more components of greater sophistication. The FS-X program represents a new stage of joint development, with the Japanese firm MHI acting as the prime contractor and Japanese firms taking on a much larger role in design from the outset. Independent Japanese programs have centered on trainers and day fighters, rather than the highest-technology military aircraft (see Table 2-3). Over the past 40 years or so, Japan has pursued an incremental approach to building its industry by maximizing and expanding its participation through linkages primarily with U.S. firms and consistent with U.S. government policy encouraging military cooperation.

The Aircraft Promotion Law of 1958 established the policy framework for promotion of commercial aircraft production. Although Japan did make one attempt (the YS-11) to develop a commercial aircraft, the 64-seat, twin-engine turboprop was a failure in the market.[6] Since that time, all major commercial transport aircraft programs in which Japan has participated have involved technology linkages with foreign firms. Japanese firms progressed from work as subcontractors on Boeing's 747, 727, and 737 models and on McDonnell Douglas's DC-9 and DC-10 during the late 1960s and early 1970s to "risk-sharing subcontractors" involved in the development and production of the 767 in the late 1970s. These linkages are explored in more detail in the next chapter.

## U.S. AND JAPANESE POLICIES

*Japanese and U.S. government policies toward the aircraft industry provide striking contrasts.* The contextual changes mentioned above are forcing adjustments in both countries, and in many ways the 1990s are a watershed period. Critical choices made today will have significant impacts for many years to come.

As a basis for comparison, a number of policy vehicles are examined briefly, along with the overall process of decision making. The policy instruments include direct financial assistance, support for civilian R&D, military and civilian procurement synergies, and other forms of government action to

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[5]Richard Samuels points out that despite the formal ban, 40 percent of the facilities were maintained and 80 percent of the engineers stayed on at IHI and Nakajima. Ibid., chapter 7.

[6]Only 182 planes were sold and the government forgave a large debt. MHI and FHI made several attempts to enter the smaller business-class aircraft segment without success.

**TABLE 2-3** Japan's Postwar Military Aircraft Programs (Excluding Helicopters)

| Program | Manufacturer/Partner, Linkage | Period | Number Produced |
|---|---|---|---|
| Independent Japanese Programs | | | |
| T-1A/B | Fuji Heavy Industries (FHI) | 1955-1962 | 60 |
| PS-1 | ShinMaywa Industries | 1965-1978 | 23 |
| US-1 | ShinMaywa Industries | 1973-present | 14+ |
| T-2 | Mitsubishi Heavy Industries (MHI) | 1970-1987 | 97 |
| F-1 | Mitsubishi Heavy Industries | 1974-1976 | 77 |
| C-1 | Kawasaki Heavy Industries (KHI) | 1971-1981 | 29 |
| T-4 | Kawasaki Heavy Industries | 1985-present | 76+ |
| Programs with American Participation | | | |
| F-86F | MHI-North American, licensed production | 1955-1960 | 300 |
| T-33 | KHI-Lockheed, licensed production | 1954-1959 | 210 |
| F-104J | MHI-Lockheed, licensed production | 1960-1966 | 210 (20 FMS) |
| F-4EJ | MHI-McDonnell, licensed production | 1968-1980 | 138 (2 FMS) |
| F-15J/DJ | MHI-McDonnell, licensed production | 1977-present | 250+ (14 FMS |
| P-3C | KHI-Lockheed, licensed production | 1978-present | 75+ |
| FS-X | MHI-Lockheed, codevelopment | 1987-present | ? |

NOTE: "FMS" refers to the U.S. foreign military sales program—these aircraft were direct sales unde
taken in addition to those produced under license.

SOURCE: Compiled from various sources by the National Research Council Working Group on U.S
Japan Technology Linkages in Transport Aircraft.

organize the industry, set overall national goals, and develop the aviatio infrastructure.

*In Japan, direct and indirect financial assistance has been an importa policy instrument for government support of the commercial aircraft industr* The second Aircraft Promotion Law of 1958 set the policy framework for pro moting the civilian aircraft industry. One concrete manifestation was the o ganization by the Ministry of International Trade and Industry (MITI) of th Nippon Aircraft Manufacturing Company, a consortium of MHI, KHI, FH ShinMaywa Industries, Showa Aircraft, and Japan Aircraft, to build the YS-1 in which the government held half the equity. MITI provided more than half the development costs and even guaranteed coverage of losses that the compa nies incurred in the production phase. Another example was the formation i 1971 of Japan AeroEngines, a consortium of IHI, MHI, and KHI, to develop high-bypass engine. Once again, MITI covered half the development costs wi success-conditional loans.[7] Beginning in the early 1970s, MITI provided su cess-conditional loans for Japanese partnerships with Boeing as risk-sharin subcontractors in a development program that ultimately became the Boein

[7] Success-conditional loans are repaid as the borrower earns revenue on the targeted project.

767.[8] In 1986, the Japanese government supported the initiation of Japanese partnership with Boeing in the 7J7 project (later put on hold) to develop a narrow-bodied civil transport. In FY 1993, the government of Japan reportedly provided 2 billion yen ($16 million) for the 777 project,[9] as well as loans from the Japan Development Bank (JDB) and the Export-Import Bank for development and for aircraft imports.[10]

The International Aircraft Development Fund (IADF), since its establishment in 1986, has been a major vehicle for government support of Japanese participation in new international commercial aircraft programs. Establishment of the IADF reflected MITI's decision in the 1980s to foster international collaboration as the major mechanism for strengthening Japan's domestic aircraft industry. The IADF, supported by corporate member contributions and indirect government aid,[11] distributes interest-free loans that must be repaid out of revenue from the project.[12] Although the Japanese financial contributions to a large project such as the 777 make up only a portion of the total, it is a significant portion. The Japanese are risk-sharing partners developing 20 percent of the airframe for the 777 project, which may cost as much as $5 billion; in addition, support from the government (in the form of loans from the JDB and indirectly through the IADF) may well total $300 million to $400 million annually for the project, not to mention JDB and Export-Import Bank loans for aircraft imports that provide revenues to Boeing. Direct financial support brings benefits to foreign as well as Japanese firms (see Table 2-4).

Direct financial assistance to the commercial aircraft industry has not been a major U.S. policy instrument. During the postwar period, such assistance has been extended on three occasions—$1 billion for development of the supersonic transport in the 1960s, and loan guarantees (never actually called upon) to two struggling aircraft producers. The Office of Technology Assessment (OTA) observes that these examples "pale in comparison" to direct financial assistance by other governments and that the interventions "were ad hoc, not a part of a coherent strategy to support the commercial aircraft industry." [13]

Reflecting differences in government policies and corporate practices, the Japanese aircraft industry made comparatively large investments in capital spending. In 1990 the U.S. aerospace industry invested $3.4 billion (2.7 percent of sales) in capital spending, while the Japanese aerospace industry spent $1

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[8]Loans from MITI totaled 14.7 billion yen for the development phase. According to MITI officials, the loans were more than 90 percent repaid by the summer of 1993.

[9]*Wing Newsletter*, January 13, 1993, p. 7.

[10]JDB loans in the amount of almost $1 billion were allocated for the V2500, 777, and 7J7 projects.

[11]In FY 1992, 4.3 billion yen (about $40 million) was provided through MITI's budget for the V2500, 777, and YXX programs. See Nihon Kokuchukogyokai, op. cit., p. 426.

[12]See Samuels, op. cit., chapter 7, for a more detailed analysis of Japanese government support for the Japanese aircraft industry.

[13]U.S. Congress, Office of Technology Assessment, op. cit., p. 348.

**TABLE 2-4** Fiscal 1993 Japanese Government Aircraft Industry Support (million dollars, ¥110 per dollar)

| | | |
|---|---|---|
| *R&D and Program Support* | | |
| MITI total | 92.5 | |
| V2500 | 19.3 | |
| 777 | 18.2 | |
| YXX | 5.3 | |
| HYPR | 36.8 | |
| SST market studies | 1 | |
| Advanced heat-resistant materials | 16 | |
| Small airplane studies | 1 | |
| Small engine research | 0.1 | |
| Test facilities | 0.1 | |
| (program support includes $5.5 million from non-MITI sources) | | |
| Japan Development Bank Loans | | |
| V2500, 777 and YXX | 1,091 | (1) |
| Science and Technology Agency | | |
| National Aerospace Laboratory | 66 | (2) |
| Japan Defense Agency | 1,091 | (3) |
| *Other Support* | | |
| Japan Development Bank and Export-Import Bank loans for aircraft imports | 1,597 | |

NOTES: (1) The JDB figure is the total available—it is possible that not all of this will be lent. (2) According to the National Aerospace Laboratory (NAL), NAL budget reporting significantly states aeronautics funding because most personnel and overhead costs for both aeronautics and research are reported under aeronautics. NAL aeronautics R&D funding minus overhead and sa was about $3 million in 1993. (3) The figure given here is the budget for the Japan Defense Age Technical Research and Development Institute (TRDI). In 1992, over half of TRDI's budget toward research contracted to industry in connection with the FS-X codevelopment program.

SOURCE: *The Wing Newsletter*, January 13, 1993, pp. 7-8; Communication from National Aero Laboratory, July 1993; Science and Technology Agency, *Indicators of Science and Technology* (Tokyo: Okurasho Insatsukyoku, 1993), p. 125; and Japan Defense Agency, November 1993.

billion (10 percent of sales).[14] Capital equipment spending will have long-t payoffs in improved production. Furthermore, high capital expendi encourages important forms of technological change that are not capture the R&D figures.

Large capital equipment purchases enable the Japanese firms to m quickly in adopting new, advanced production methods. The manufactu work closely with the equipment suppliers in this process. As discussed late this report, this focus on technical change in the manufacturing process is

[14]See AIA, op. cit., p. 160; and Nihon Kokuchukogyokai, op. cit., pp. 430, 437.

sistent with the Japanese emphasis on cost and quality in production (rather than on overall product design) (see Tables 2-5 and 2-6).

*The Japanese government promotes diffusion of technology through cooperative civilian R&D projects.* During the 1980s the government of Japan launched a number of R&D consortia designed to develop new technologies needed in the aircraft industry, particularly engines. The advanced turboprop engine project, for example, was supported as a Key Technology Center project beginning in 1986. The Frontier Aircraft Basic Research Center Company was established to carry out the work with 70 percent equity participation by the Key Technology Center (under MITI and the Ministry of Posts and Telecommunications) and the remaining equity provided by the 34 participating firms,

**TABLE 2-5** 1991 Capital Spending (million dollars, ¥110 per dollar)

| | Total | Percentage of Sales |
|---|---|---|
| U.S. aerospace industry | 4,040 | 2.9 |
| Japanese aerospace industry | 852 | 8.2 |

NOTE: U.S. figure for SIC codes 372 and 376. Japanese figures represent the results of a survey of 24 companies. Both sets of figures may, therefore, undercount total aircraft-related capital expenditure by not including a number of supplier firms.

SOURCE: Aerospace Industries Association, *Aerospace Facts and Figures 1992-1993* (Washington, D.C.: AIA, 1992) p. 160; and Nihon Kokuchukogyokai (Society of Japanese Aerospace Companies), *Heisei Yonendohan Kokuchukogyo Nenkan* (Aerospace Industry Yearbook 1992 Edition), (Tokyo: Koku Nyusu, 1992), pp. 430, 437.

**TABLE 2-6** New Plant and Equipment Expenditures by U.S. Business (percentage change from preceding year in current dollars)

| | Actual 1991 | Actual 1992 | Planned 1993 (July-August 1993 survey) |
|---|---|---|---|
| All industries | -0.8 | 4.6 | 7.1 |
| Manufacturing | -5.1 | -4.8 | 3.4 |
| Aircraft | 0.8 | 7.6 | -22.1 |

SOURCE: U.S. Department of Commerce, Bureau of the Census.

which included auto and machinery makers and materials fabricators.[15] project, which ended in 1993, was carried out through distributed research sharing of results. The project paid for new testing equipment eventually so the participants on depreciated terms at the end of the project. Another Technology Center project beginning in 1989 focused on fabrication and de technologies for aluminum-lithium alloys. Although aircraft manufacturers not shareholders, the project provides investment funding to the alumi manufacturers and fabricators for research likely to have important applicat in the aircraft industry. Projects such as these promote the diffusion of kn how not only throughout the aircraft industry, but also through related in tries, and divide the research work in ways that create niches of unique ex tise for various corporate participants.

*International partnerships are used strategically to foster technology quisition.* Japanese government agencies have sponsored two R&D consort the engine field. The first, the JFR-710 project, supported by the Nati Aerospace Laboratory as an experimental development project in the 19 provided the foundation for Japanese participation in the V2500 project.[16] M recently, MITI launched the HYPR program in 1989, designed from the sta an international collaborative effort in supersonic engine technologies. Sc uled to continue until 1996, the project is funded by MITI at a level of a $37 million in FY 1993 and administered through MITI's Agency for In trial Science and Technology and the New Energy and Industrial Techno Development Organization. The aim is research and scale demonstration Mach 5, methane-fueled, combined-cycle engine. The major Japanese com nies (IHI, MHI and KHI) participate, along with foreign firms, which mak a total of 25 percent participation.[17] The Japanese firms are the lead compa teaming with foreign firms for various aspects of the development project Figure 2-1). The HYPR project is important as Japan's first attempt to orga and lead an international collaborative effort to develop advanced avia technology. The project is also important because the Japanese governm eventually revised its legislation on intellectual property rights, allowing eign firms ownership in response to jointly organized representation from foreign firms.[18]

The U.S. government funds R&D for civil applications through the tional Aeronautics and Space Administration's (NASA) aeronautics prog (see Tables 2-7 and 2-8). Although research supported by NASA has prod many advances, a recent National Research Council (NRC) report concl that "the attention paid to civil aeronautics in the NASA budget is

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[15]See Samuels, op. cit., chapter 8, for a more detailed analysis of the FARC project. Inform about the Key Technology Center projects here is based on Samuels' more extensive analysis.

[16]David C. Mowery, *Alliance Politics and Economics: Multinational Joint Ventur Commercial Aircraft* (Cambridge, Mass.: Ballinger Publishing Company, 1987), pp. 91-92.

[17]Foreign firms participating are United Technologies, GE, Rolls Royce, and Snecma.

[18]The U.S. Department of State approves export licenses for technology transfer by partici U.S. companies.

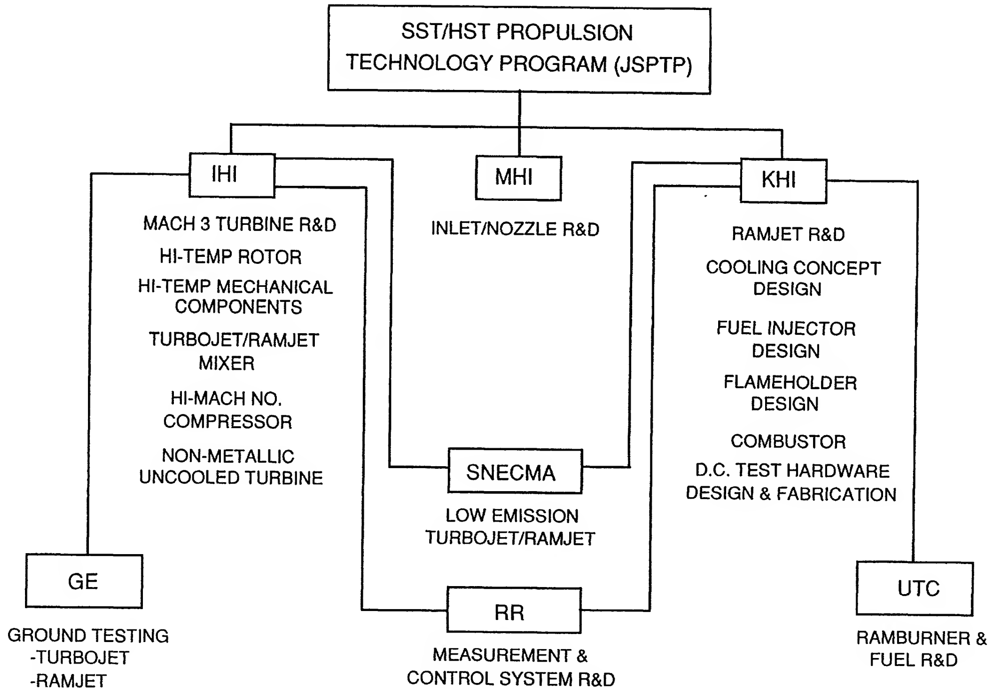


**FIGURE 2-1** HYPR Technical R&D Responsibilities. SOURCE: Pratt & Whitney.

**TABLE 2-7** NASA Aeronautics Programs (million dollars)

| Category | 1993 | 1994 |
|---|---|---|
| Research and development | 717 | 957 |
| Aeronautics | (555) | (877) |
| National Aerospace Plane | (4) | (80) |
| Research operations support | 149 | 144 |
| Research and program management[a] | 303 | 318 |
| Construction of facilities | 65 | 212 |
| Total | 1,234 | 1,631 |

[a]Includes aeronautics and national aerospace plane portions.
SOURCE: National Aeronautics and Space Administration.

**TABLE 2-8** U.S. Government Outlays for Aeronautics R&D (million dollars)

| Agency | 1991 |
|---|---|
| NASA (includes research and program management) | 1,017 |
| Department of Defense | 6,792 |
| Department of Transportation (FAA) | 1,870 |
| Total | 9,679 |

NOTE: NASA figure includes research and development, construction of facilities, research and gram management. Department of Defense figure includes research, development, and test and ev tion of aircraft and related equipment. Federal Aviation Administration figure includes research, neering, and development; and facilities, engineering and development.
SOURCE: National Aeronautics and Space Administration, "Aeronautics and Space Report o President" (annual), appearing in Aerospace Industries Association, *Aerospace Facts and Fig 1992-1993* (Washington, D.C.: AIA, 1992).

commensurate with the importance the industry plays in the natio economy." The NRC committee recommended that NASA review its bu and emphasize the development of technologies that will make aeronautical products more competitive.[19] NASA's total budget for aeronaut R&D was $574 million in 1992; about 17 percent went to R&D contracted industry.

Although there have clearly been cases where NASA-supported progr have produced technological advances that have enhanced the competitive

[19]National Research Council Aeronautics and Space Engineering Board, *Aeronau Technologies for the 21st Century* (Washington, D.C.: National Academy Press, 1992), p. 7.

of U.S. firms,[20] *there has been no comprehensive effort directed toward technology commercialization and product application technology.* While some identify NASA's civil aeronautics program with industrial policy, there is growing interest today in coupling NASA's R&D more closely to industry, a theme that NASA took up in 1993.[21] Although Japan's National Aerospace Laboratory is funded at an annual level of about $100 million or less than one-fifth of NASA's budget for aeronautical R&D,[22] it does support some work in areas such as composite materials important to the future commercial aircraft industry. *Japan's government-supported domestic cooperative programs, particularly those supported by MITI, are more strongly oriented to technology sharing among Japanese companies and commercialization of technologies for commercial aircraft than those supported by the U.S. government* (see Tables 2-9 and 2-10).

The U.S. government has, however, played a major role in encouraging the development of air transportation, making the United States a leading market. This role constitutes an important source of indirect support for U.S. aircraft manufacturers. The main channels of support have been the Federal Aviation Administration (FAA) activities to ensure safety and to develop the air traffic infrastructure, and regulation of fares and routes by the Civil Aeronautics Board prior to its abolishment in 1978 with deregulation. With deregulation, the aircraft manufacturers lost the advantages of cooperation with deep-pocketed lead users (the airlines) who articulated demand and pushed product development. Although virtually all analysts agree that travelers have benefited from lower fares in the post-1978 period as increased competition has led airlines to reduce costs, current convulsions and heavy financial losses in the airline industry have caused some concerns about instability in the industry and raised doubts about the prospects for adequate long-term profitability.

**TABLE 2-9** United States Aerospace Industry R&D Spending (million dollars)

| | 1988 | 1989 | 1990 |
|---|---|---|---|
| Total | 25,900 | 25,638 | 25,357 |
| Federal Source | 19,877 | 19,633 | 19,217 |
| Industry Source | 6,023 | 6,005 | 6,140 |

SOURCE: Aerospace Industries Association, *Aerospace Facts and Figures 1992-1993* (Washington, D.C.: AIA, 1992), p. 105.

[20]OTA, op. cit., p. 347.

[21]Kathy Sawyer, "Reviving Aeronautics—Space Agency Focuses on Global Context," *The Washington Post*, May 27, 1993, p. A23.

**TABLE 2-10** Japanese Industry's Intramural Aircraft-Related R&D Spending[a] (million dollars, ¥110 per dollar)

| Industry Sector | Aircraft-Related R&D Spending (% of total) 1990 | | 1991 | |
|---|---|---|---|---|
| Total[b] | 442.6 | (100%) | 525.8 | (100% |
| Autos | 82.1 | (19%) | 67.9 | (13%) |
| Other transportation equipment | 298.7 | (68%) | 408.7 | (78%) |
| Aircraft and Parts | [18.2 | (4%)] | [21.8 | (4%)] |
| Other industries[c] | 61.8 | (14%) | 49.2 | (9%) |

[a]Includes government funds spent by industry. [b]Total may not be exact due to rounding.
[c]Other industries conducting aircraft-related R&D during 1990 and 1991, none of which const more than 5 percent of the total, were textiles, chemicals, plastic products, rubber products, steel, no rous metals, machinery, electronic machinery, precision machinery, other manufacturing, and tran tation/telecommunications/utilities.

SOURCE: Somucho Tokeikyoku (Management and Coordination Agency, Statistics Bureau), *Ka Gijutsu Kenkyu Chosa Hokoku—Heisei Sannen, (Report on the Survey of Research and Dev ment 1991)*, (Tokyo: Nihon Tokei Kyokai, 1992), pp. 162-163; Somucho Tokeikyoku (Manage and Coordination Agency, Statistics Bureau), *Kagaku Gijutsu Kenkyu Chosa Hokoku—Heisei Y (Report on the Survey of Research and Development 1992)*, (Tokyo: Nihon Tokei Kyokai, 1993 162-163; and Communication from the Management and Coordination Agency, Statistics Bu September 2, 1993.

U.S. government financing of aircraft exports at low interest rates thro the U.S. Export-Import Bank provided strong support for the aircraft manu turers in the 1970s. "Wars" over export financing were mitigated by the L Aircraft Sector Understanding of the late 1970s, which set floors on accept interest rates. New financing techniques have, moreover, made private bor ing more feasible to purchase aircraft. In Japan, the Japan Development E and the Export-Import Bank continue to support aircraft imports with l totalling $1.9 billion appropriated in 1992.[23] In recent years, The U.S. Exp Import Bank has again become important to aircraft exports (see Table 11and 2-12).[24] Some have called for an increase in its budget for this purpos order to address the current aircraft sales slump. Aircraft exports fell 15 per in the first quarter of 1993, to $9.6 billion.[25]

[22]See NRC, op. cit., p. 8; and National Aerospace Laboratory 1991-1992 (program brochur 4. The $100 million budget includes personnel as well as research and facilities for space and ai R&D.

[23] See Nihon Kokuchukogyokai, op. cit., p. 426.

[24]In August 1993, it was reported that the Export-Import Bank would provide loan guarante sales of aircraft to Saudi Arabia valued at more than $6 billion. See John Mintz and Ruth M "Saudis Shift Jetliner Order to U.S.," *The Washington Post*, August 20, 1993, p. B1.

[25]AIA, news release, June 16, 1993.

**TABLE 2-11** U.S. Export-Import Bank (million dollars—1991)

| | |
|---|---|
| Total loan authorizations | 604 |
| Loan authorizations supporting commercial jets | 0 |
| Total guarantee authorizations | 6,016 |
| Guarantee authorizations supporting commercial jets | 566 |

NOTE: Commercial jet category includes complete aircraft, engines, parts, and retrofits.

SOURCE: Aerospace Industries Association, *Aerospace Facts and Figures 1992-1993* (Washington, D.C.: AIA, 1992), p. 134.

**TABLE 2-12** U.S. Export-Import Bank 1992 Guarantees Supporting Commercial Jets (million dollars)

| Country | Number | Type | Guarantee |
|---|---|---|---|
| Brazil | 2 | B-737 | 42.3 |
| Mexico | 1 | B-737 | 30.4 |
| Tanzania | 2 | B-737 | 52.8 |
| Morocco | 4 | B-737 | 114.1 |
| Chad | 5 | B-737 | 122.6 |
| India | 4 | B-747 | 600.0 |
| Norway | 2 | B-737 | 42.3 |
| Pakistan | 1 | B-737 | 30.0 |
| China | 1 | MD-11 | 94.5 |
| Australia | 5 | B-737 | 130.7 |
| Poland | 9 | B-737 | 246.1 |
| China | 1 | MD-11 | 91.3 |
| Total | 37 | | 1,597.1 |
| (Export Value) | | | (1,889.1) |
| Total Guarantee Authorizations | | | 7,301 |

SOURCE: Aerospace Industries Association and U.S. Export-Import Bank.

Like the United States, Japan is a signatory of the General Agreement on Tariffs and Trade and imposes no formal quotas on aircraft imports or formal offset requirements to increase Japanese-supplied content. Japan's three major airlines are now all formally private entities. However, U.S. manufacturers selling to Japan do feel informal pressures to source some parts in Japan in or-

der to enhance access to Japanese airlines. The Ministry of Transportation h
a major influence on the industry through its regulation of routes and fares.

The Treaty of Mutual Security and Assistance with the United Stat
Japan's only formal security treaty, is the bedrock of the defense relationsh
This 40-year-old treaty[26] remains critically important to the overall bilate
relationship, although there is also a growing belief in the United States tl
the nature of the alliance will undergo change. The combination of thre
reduction in Asia stemming from the end of the Cold War and budgeta
pressures in the United States suggests that U.S. troop deployments in Asia w
continue to decline, a prospect that worries some Japanese and other Asi
allies. However, President Clinton's stress on the commitment of the Unit
States to active engagement in the region and to multilateral discussions
security was well received in Japan.[27]

Military R&D and procurement constitute an area where U.S. and Japane
policies differ markedly. The U.S. Department of Defense (DOD) alone spe
almost $7 billion in research, development, construction of facilities, and pr
gram management on aeronautics R&D in 1991 (see Figures 2-2 and 2-3).[28]
pan's defense budget, compared to that of the United States, allocates a smal
share to R&D. In 1992, for example, the ratio of capital equipment expenditu
(including weapons procurement) in JDA's budget was 31 percent as contrast
to 2.5 percent for R&D (see Table 2-13). In the United States, the federal ae
nautics budget for R&D was $9.6 billion and the total defense budget $2
billion.[29] Despite the fact that JDA's direct R&D funding is small, howev
TRDI (JDA's Technical Research and Development Institute) focuses this eff
on technologies that contribute to the overall industrial base. For example, e
phasis on radar development and composite materials reflects an assessme
that these technologies will have wide applications in both nondefense and
fense areas.[30] In contrast, the DOD budget has focused increasingly in the l
15 years on areas such as stealth technologies that have no immediate applic
tions to commercial aircraft. On the one hand, a higher percentage of aircr
production directed to military demand in Japan as compared to the Unit
States suggests a strong effect on capital equipment spending by JDA. On t
other hand, Japanese companies finance a large share of their R&D inve
ments with their own funds, with the expectation of large, lucrative JDA p
curement down the line.

In the early postwar period, as mentioned earlier, Japan's military aircr
industry was reborn on the basis of production licenses from U.S. firms, nego
ated with the support of the U.S. government. Since the 1970s, the Unit

[26]The treaty was modified in 1960.

[27]See, for example, Ruth Marcus, "Summit a Winner for Clinton," *The Washington Post*, July
1993, p. A1.

[28]AIA, *Aerospace Facts and Figures 1992-1993* (Washington, D.C.: AIA, 1992), p. 108.

[29]Outlays by NASA, DOD, and the Department of Transportation. Ibid. pp. 18 and 108.

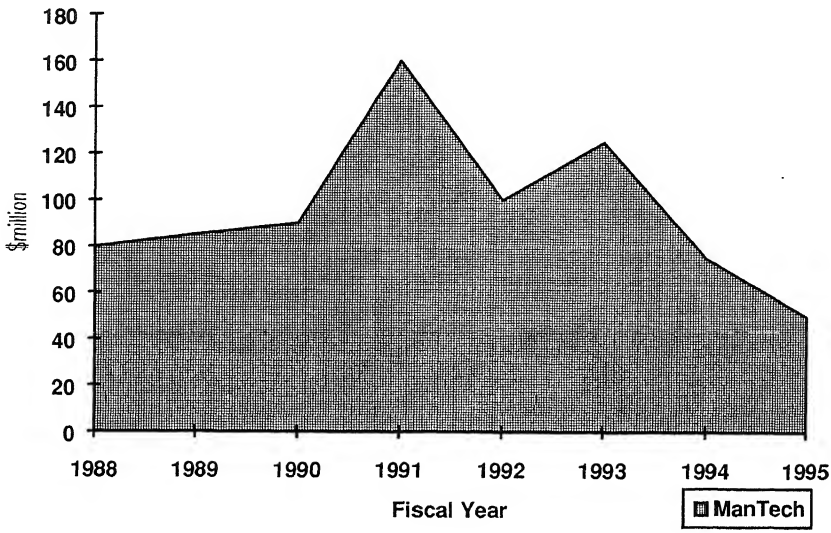


**FIGURE 2-2** DOD manufacturing technology—fixed-wing aircraft. NOTE: ManTech shown for fixed-wing is about 50 percent of total ManTech. SOURCE: U.S. Department of Defense.

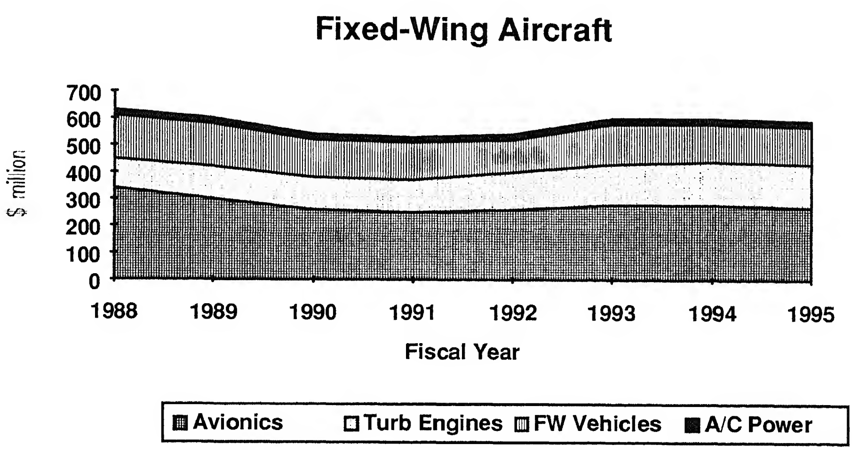


**FIGURE 2-3** Aeronautical core R&D funding—fixed-wing aircraft. NOTE: Tech demos, dem/vals not included. Avionics include sensors, ASW, and EW technologies.

**TABLE 2-13** Japan's Defense Budget for Fiscal 1993 (million dollars, ¥110 per dol

| | Amount | Percentage of Total |
|---|---|---|
| Personnel, provisions | 17,632 | 41.8 |
| Materiel | 24,552 | 58.2 |
| Equipment | 9,811 | 23.3 |
| R&D | 1,125 | 2.7 |
| Facilities | 1,821 | 4.3 |
| Maintenance | 6,855 | 16.3 |
| Base countermeasure costs | 4,401 | 10.4 |
| Other | 540 | 1.3 |
| Total | 42,187 | 100 |

SOURCE: Boeicho (Japan Defense Agency), ed., *Heisei Gonen Boei Hakusho* (1993 Defense W Paper), (Tokyo: Okurasho Insatsukyoku, 1993), p. 333.

States has attempted to increase the flow of defense-related technology fr Japan. Despite the 1983 exchange of notes in which Japan agreed to exempt United States from its political prohibition on military technology exports, a the work of the U.S.-Japan Systems and Technology Forum, the results ha fallen far short of expectations. There are a number of possible explanatio including a lack of understanding about what the United States wants from pan, as well as Japanese reluctance to transfer technologies to the United Sta that might be incorporated into weapons systems and retransferred abroad.

Japan has strongly emphasized dual-use facilities in its defense R&D. deed, Japan's world-class commercial industrial base is seen as the foundat for military production. A former director of the TRDI, JDA's R&D institu has noted that in technology there is no black or white, only gray—it becor military or civilian in application.[31] Japan's approach to military R&D has be not to focus on technology breakthroughs, but rather to stimulate industr sectors and technologies that have a wide range of applications, carefully ranging for a division of labor among companies that promotes building specialized skills that complement those of other firms. Japanese compan have developed substitute components for weapons systems licensed from United States (either because the components were "black boxed" and Jap wished to develop independent technology or as improvements on U.S.-ori technologies). These components are commonly derived from commerc products, often without Japanese government funding. In general, the Japan consider these technologies to be nonderived and interpret provisions exemption of commercial technologies from technology flowback arrangeme with the United States quite broadly.

[31]Ibid., p. 36.

*Although there are sharp contrasts in the nature of military-civilian interface in the two countries, the committee concludes that Japan does a better job of effectively utilizing its resources to promote synergies between military and civilian aircraft production.* DOD procurement practices pose significant obstacles to companies that wish to promote military-civilian synergies. Accounting practices, military specifications, unique contract requirements, and policies on technical data rights all inhibit interactions and force companies to use separate plant facilities.[32] The large amount that DOD spends on R&D compared with the Japanese government clearly benefits U.S. industry in supporting its technology base, but the synergy between U.S. military and commercial technology has been declining.[33] In contrast to DOD's support in years past for technologies (jet engines and swept back airfoils) with both military and defense applications, during the past 15 years, DOD has oriented its support to defense-unique technologies such as stealth and high maneuverability.

In Japan, while there also exist some obstacles to military-civilian interactions related to military specifications and procurement practices, there are offsetting factors. The fact that military aircraft production is carried out by large Japanese companies with diversified production in other sectors, as well as the colocation of military and civilian production lines create opportunities for cross-fertilization of manufacturing know-how and sensitivity to the potential applications of technologies developed on the commercial side. Japan's procurement system helps to reinforce "technology highways" that link larger companies with suppliers, integrate military and civilian production, and foster an integrated and flexible dual-use technology and industrial base. In Japan, technological and commercial competence is as much a matter of national security as force deployment.[34]

Dramatic cuts in the U.S. defense budget in recent years have resulted in a fundamental restructuring within the industry and companies engaged in military production are pursuing a combination of downsizing, consolidation, diversification, and exit strategies. In Japan, industry observers are also worried about declining defense procurement, which is expected to hit the industry hard in the mid-1990s.[35] The push toward commercial production is thus a clear im-

[32]Report of the Center for Strategic and International Studies Steering Committee on Security and Technology, *Integrating Commercial and Military Technologies for Military Strength* (Washington, D.C.: CSIS, 1991).

[33]See John A. Alic, Lewis M. Branscomb, Harvey Brooks, Ashton B. Carter, and Gerald L. Epstein, *Beyond Spinoff: Military and Commercial Technologies in a Changing World* (Boston, Mass.: Harvard Business School Press, 1992).

[34]For a detailed analysis of Japan's "technology highways" and the "protocol system" among companies, see Samuels, op. cit., chapter 8; and David B. Friedman and Richard J. Samuels, "How to Succeed Without Really Flying: The Japanese Aircraft Industry and Japan's Technology Ideology," in J. Frankel and M. Kahler, eds., *Regionalism and Rivalry: Japan and the U.S. in Pacific Asia* (University of Chicago Press, 1993).

[35]In FY 1991, JDA's defense acquisition budget was cut 16.1 percent over the previous year. The

perative in both countries. One key question is whether Japan's aircraft indu
try may be particularly well positioned to capture increasing shares of the a
craft and commercial engine components manufacturing, and repair markets
the future. Based on examination of the policies (public and private) that ha
fostered close integration of large and small companies, flexibility of capi
equipment, and tight coupling of defense and commercial production, t
committee judges it likely that the already apparent trends of increasing Jap
nese shares in these areas, particularly components manufacturing and rep
markets, will continue in the future.

Planners in both Japan and the United States, attempting to adjust to t
dramatic changes mentioned at the outset, are considering new approaches.
the United States, the Advanced Research Projects Agency (ARPA) is leading
new set of programs aimed at fostering defense conversion, while DOD's lea
ership is focusing on reducing barriers between military and civilian producti
through streamlined procurement in the context of a lower defense budget, a
NASA has announced a new stress on aeronautical R&D. Meanwhile, a co
mission on the future of the airline industry has recommended policy chang
relevant to that industry.[36] In the United States, the approach to policy redire
tion appears to be largely ad hoc and uncoordinated, whereas Japan's decisio
making agencies are fewer in number and work together to formulate a co
mon vision for the industry.

These differences have significant implications for U.S. and Japanese co
panies interested in forming partnerships. *A Japanese company interested
forming a technology linkage with a potential U.S. partner coordinates with
smaller number of key actors in government than does the U.S. company* (s
Table 2-14).

Within the government, MITI is the major player, but interactions wi
JDA are also required with respect to military programs. MITI's Aircraft a
Ordnance Division, which plays the central role in policy formulation, h
shifted policy focus on "national production" (*kokusanka*) to international joi
ventures.[37] Japan's major aircraft companies and suppliers are members of t
Society of Japanese Aerospace Companies (SJAC), which sometimes acts
coordinator (as has been the case with the international consortium on co
mercial aircraft components and foreign missions such as the recent trip
Russia) and Keidanren's Defense Production Committee. In contrast to t
situation in the United States, the number of actors is smaller, the major playe

---

1991-1995 plan. Japanese defense planners worry that procurement of two in FY 1993 will account
a large share of JDA's total defense procurement budget for all services. See Barbara Wann
"Japanese Defense Industry Grapples with Post-Cold War Conversion," *JEI Report*, No. 12A, April
1993.

[36]See National Commission to Ensure a Strong Competitive Airline Industry, *Change, Challe
and Competition: A Report to the President and Congress* (Washington, D.C.: U.S. Governm
Printing Office, 1993).

**TABLE 2-14** Major Policy Checkpoints for Companies Forming International Technology Linkages

| Government | Industry |
|---|---|
| *Japan* | |
| MITI | SJAC |
| Aircraft and Ordnance Division | |
| Aircraft Industry Council | |
| AIST | |
| JDA | Keidanren Defense Production Committee |
| Equipment Bureau, Aircraft Division | |
| Procurement Office | |
| TRDI | |
| Air Self-Defense Staff Tech Department | |
| STA | |
| National Aerospace Laboratory | |
| *Related Organizations* | |
| IADF | |
| *United States*[a] | |
| Department of Commerce | AIA |
| International Trade Administration, | American League for Exports and Security Assistance |
| Aerospace, Trade Development | |
| International Economic Policy, Japan | |
| Bureau of Export Administration | |
| Industrial Resources Administration | |
| National Security Preparedness Division | |
| Technology Administration | |
| Department of Defense | |
| International Security Affairs, Japan Desk | |
| Defense Security Assistance Agency | |
| Acquisitions, International Programs | |
| ARPA | |
| Defense Technology Security Assistance Administration | |
| Military Services | |
| Department of State | |
| Bureau of East Asia-Pacific, Political Affairs | |
| Bureau of Political Military Affairs, National Security | |
| Defense Relations, Security Assistance | |
| Center for Defense Trade | |
| Bureau of Economic and Business Affairs | |
| U.S. Trade Representative | |

[a]Consultations differ, depending on the program. The FS-X project involved consultations with most of these agencies.

SOURCE: Based on memos provided to the committee by Michael Green and Gregg Rubinstein.

overlap, and the process is oriented toward quiet advance coordination am business and government.

A U.S. company considering a technology linkage with a Japanese co terpart interacts with a more complex maze of U.S. agencies and regulations the case of a military project, the company must consult with a variety of off within DOD, including the Japan desk of what is now Regional Secu Affairs; the Defense Security Assistance Agency (DSAA), which coordin defense sales and licensed production; and the Defense Technology Secu Administration, which oversees technology transfer and export licenses DOD.[38] All military export applications are submitted to and approved by Department of State, Office of Defense Trade Control. For military commercial projects, a U.S. company is well advised to consult with Department of Commerce (the International Trade Adminstration and Bureau of Export Administration) as well as the State Department.

Under normal procedures, approval of licenses is handled by the licens offices of the various departments in coordination with the relevant prog offices and country desks. However, official evaluation of military aircraft grams is complicated by the arbitrary division of responsibility in DOD sales/licensed production and cooperative R&D programs in two separate often uncoordinated bureaucratic entities (Undersecretary for Policy, DS and the Undersecretary for Acquisition, Dual-use Technology Policy & In national Programs). This has often led to inconsistency in DOD positions Japan programs, as well as problems in coordinating with other agencies. increased role of the Department of Commerce in recent years reflects a rec nition that the U.S. industrial/technology base is both a defense and an nomic policy concern, but in practice, effective coordination among D Commerce, and State is often difficult. In controversial cases, senior execu branch officials participate in an interagency process coordinated through National Security Council or the National Economic Council and draw the tention of members of Congress and research organizations such as the Gen Accounting Office.[39]

In Japan, the process of policy evaluation and adjustment is also multi eted, but the locus of activity is clear: MITI and the industry. Japanese indu and government became more realistic in the 1980s concerning obstacle becoming a world-class player in aircraft; MITI can not and does not direct industry, but develops policy jointly with industry. Compared to other sec such as computers and semiconductors, which are also the focus of pol MITI has considerable influence over the aerospace industry because industr

[38]In addition, the Office of International Programs has jurisdiction relating to R&D program does ARPA potentially), and consultations with the military services are essential for all cooper

still highly dependent on JDA procurement, has not moved offshore, and is restricted from defense exports.

Japanese government and industry continue to look ahead to the future, planning new programs and policy adjustments. In past months, a series of new studies, working groups and international missions have been organized to consider critical decisions relevant to the future of the industry (see Table 2-15). For example, MITI and the Ministry of Transportation in cooperation with SJAC have formed a committee to study requirements for the High Speed Commercial Transport (HSCT). The purpose is reported as developing a "Japanese proposal" for presentation to Boeing and Airbus concerning future specifications and domestic infrastructure requirements. Meanwhile, MITI, JDA, and SJAC are reportedly formulating a domestic development program for a medium-sized transport that can be used for military and commercial purposes. JDA has set up two working groups to look at defense procurement and R&D activities in defense technology. Some of this work, such as the HSCT study, will be made public. Other activities, such as the JDA working groups, will continue discussions for a number of months with no expectation of producing published reports.

International linkages are very much a focus of planning. SJAC recently sent a mission to Russia, with a resulting plan to invite Russian engine specialists to Japan and expand access of Japanese companies to Russian test facilities.[40] Airbus has, meanwhile, expressed interest in cooperating with Japan's committee examining HSCT issues. In the context of the U.S.-Japan Systems and Technology Forum, one new cooperative project on ducted rocket engine technology was initiated and others are in the planning stage. As the development stage is completed on the FS-X, it is expected that negotiations will begin on production.

All of these efforts will feed into a process that provides Japan with the option for aircraft production in the twenty-first century. Many of the same individuals are key participants in all of the Japanese studies and missions. It may be some time before a change in Japan's official policy is formally articulated. In the meantime, a process of information gathering, foreign travel, discussion, and exchange will take place that builds a common framework for making choices. In this process, industry and government interact as partners who share a common overarching goal.

Japan has more alternatives for international partnerships than ever before in the postwar period. With whom and how to form linkages of various sorts are major considerations. Increasingly, Japanese companies are experimenting with diverse partnerships that involve more than one foreign company. Further diversification of international linkages seems likely, but geopolitical questions remain, such as whether Japan and Russia can resolve their lingering World

[40]U.S. firms are also expanding their linkages to Russia. For example, Pratt & Whitney will supply engines and Collins will supply avionics for the new Ilyushin IL-96M aircraft, which reportedly will sell at a cost far below similar sized airplanes now on the market.

**TABLE 2-15** Aircraft Industry-Related Studies in Japan

1. *Requirements for HSCT and Very Large Transport*

MITI and the Ministry of Transportation, in cooperation with SJAC, are forming a "Committ Promote the Introduction of Next-Generation Aircraft." Including representation from the four he and the three largest airlines, the committee will study demand for the superjumbo and HSCT. purpose will be twofold: (1) to present a "Japanese proposal" to airframe manufacturers concernin specifications of these future aircraft; and (2) to study the domestic infrastructure implicatio introducing them (*Nihon Keizai Shimbun*, April 13, 1993).

2. *SJAC-Russia Joint Programs*

A mid-May 1993 SJAC mission to Russia resulted in an agreement to invite Russian engine sp ists to Japan and for Japanese companies to gain access to Russian test facilities (*Japan Digest*, Ma 1993).

3. *Multipurpose Medium Aircraft*

A joint planning committee of MITI, JDA, and SJAC has reportedly been charged with formul a domestic development program for a medium-sized transport that could be used by domestic ai and by JDA for transport and antisubmarine roles. Total production volume is anticipated to be 500 (*Nikkan Kogyo Shimbun*, January 19, 1993).

4. *Second-Generation SST Studies*

Since 1987, the Supersonic Transport Development and Survey Committee of SJAC has cond studies under commission from MITI on the airframe specifications for next-generation SSTs, so key technologies could be identified and developed (*Kokusai Koku Uchu*, December 1992).

5. *YS-X Transport*

MITI funding continues for research on the 75-100 twin-turbofan. Japan would take the lead international partnership (*Aviation Week and Space Technology*, June 1, 1992).

6. *YXX/7J7 Transport*

MITI funding for this 100+ seat transport has continued, although future prospects are uncertai

7. *Study on the Future of the Japanese Aircraft Industry*

A MITI-led study was mentioned by Keidanren Defense Production Committee during a July 1993 meeting with the NRC committee.

8. *Basic Technology for Advanced Stealth Aircraft*

TRDI is reportedly proposing work on a proof-of-concept aircraft to begin as FS-X and OH-X velopment winds down in 1995 (*Aerospace Japan-Weekly*, June 14, 1993).

9. *C-X Transport and T-X Trainer*

These are indigenous aircraft programs reportedly being considered by JDA. Connection bet C-X and dual-use transport (item 3 above) is unclear (*Aerospace Japan-Weekly*, June 14, 1993).

10. *Test Facilities*

Planning continues for new aircraft and rocket engine testing facilities under the auspices of T (*Aviation Week and Space Technology*, August 24, 1992).

11. *International Composites Program*

Press reports during the summer of 1992 described a new MITI program researching applicatio lightweight composite materials for supersonic aircraft. The proposed program would run for six y cost $240 million, and be open to foreign participation (*Aviation Week and Space Technology*, Au 3, 1992).

**TABLE 2-15** *Continued*

*12. JDA Advisory Committees*

JDA's Equipment bureau has reportedly formed two advisory committees that do not appear to be connected with any particular potential program on Defense Equipment Procurement and on Defense Industry Technology. (Source: Mutual Defense Assistance Office.)

SOURCE: Compiled by National Research Council Committee on U.S.-Japan Aircraft Linkages from various sources.

War II era territorial dispute over the Northern Territories. Another consideration is whether Boeing will pursue an ever-broadening and deepening role for Japanese companies. Airbus has been exploring cooperation with Japan, with success seen in expanded sales of aircraft in recent years.

*The Japanese policy and business environment allows industry to gain maximum leverage from international alliances and procurements, resulting in a gradual upgrading of independent technological capabilities and diffusion of those skills across civilian and military production and among the major contractors and the many subcontractors in Japan's aircraft manufacturing network.* The Japanese aircraft industry does not carry out full independent integration of airframes, but it has become a major player in the subsystems and components areas and, with the support of the government, has built significant indigenous capabilities. Japan has achieved increasing independence and growing technological strength by promoting international linkages, particularly in the defense area.[41] Japan is pursuing international linkages and the development of indigenous capabilities simultaneously, skillfully managing international cooperation to derive maximum gains in terms of autonomous development.

[41]See Samuels, op. cit., chapter 8 for an analysis of "the paradox of autonomy through dependence." Samuels outlines how technology agreements permit the accumulation of skills with

# 3

# Current Status Of U.S.-Japan Linkages

Drawing on published information, briefings from experts, and its st
mission to Japan, the committee examined a wide range of U.S.-Japan techn
ogy linkages relevant to transport aircraft. The assessment included prime p
gram partnerships and government-supported R&D programs as well as re
tionships at various levels of the supplier chain. This chapter summarizes
information on linkages the committee has collected; analyzes the motivatio
mechanisms, and impacts of linkages; and highlights major themes and
sights. More detailed materials on linkages are contained in Appendixes B
C.

## AIRFRAMES

### Linkages in Commercial Airframes

The most significant U.S.-Japan linkages in the commercial airframe s
ment are the series of program-based alliances concluded between Boeing

the Japanese "heavies."[1] To all accounts, this relationship has brought significant benefits to both sides.

From the start of the 747 program in the late 1960s through the subsequent 737 and 757 programs, Boeing procured parts and equipment from Mitsubishi Heavy Industries (MHI), Kawasaki Heavy Industries (KHI), and Fuji Heavy Industries (FHI). Starting with the 767 program in the late 1970s and continuing with the 777—which is scheduled to enter service in 1995—the Boeing-Japan interaction has evolved from one in which the Japanese companies "built parts to specification" to actual design and engineering interaction from the earliest stages of product development. The work share and the technical sophistication of the manufacturing tasks undertaken by the Japanese partners have also increased steadily over time.

Boeing's primary motivation for approaching the Japanese heavies about significant participation in the 767 program was the perception that the linkage might bring market leverage. The Japanese were probably most motivated by a desire to gain access to technology as well as indirect access to the global aircraft market. MHI, KHI, and FHI designed and now manufacture approximately 15 percent of the airframe of the 767, a wide-body twinjet. As "risk-sharing subcontractors," the Japanese partners assumed the risk for their non-equity share in the program, including tooling and other investment. The Japanese government provided funding through success-conditional loans for much of this investment.

Boeing, the three heavy industry companies, and the Japanese government through the JADC negotiated a "program partnership" for the subsequent 777 program. This alliance is similar to the 767 arrangement, although Boeing originally offered the Japanese partners significant program equity participation, which they were not willing to assume. The Japanese work share in the 777 program is higher than in the 767—Japanese partners essentially build all the fuselage parts except for the nose section, as well as the wing center section, the wing-to-body fairing, and landing gear doors.[2] Indirect Japanese government support and Japan Development Bank loans have also been made available to the heavies for their participation in the 777 program.

Japanese technical responsibilities increased with the 777. There were many more Japanese engineers involved in 777 development than in 767 development, with several hundred sent to Seattle during the most intensive design phase. As was the case in the 767, the Japanese are limited in the engineering effort to their own work package.

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[1]There are three other linkages of note: (1) the Japanese heavies manufacture some components for McDonnell Douglas; (2) Mitsui & Co., McDonnell Douglas's trading company, played a key role in financing the launch of the MD-11 (more a business alliance than a technology linkage); and (3) the Toyota-affiliated Ishida Group has made several direct investments in small U.S. companies, including an undertaking to develop a tilt-rotor aircraft, which was reportedly suspended earlier this year.

[2]Japanese companies also build the wing-to-body fairing on the 767.

On both the 767 and the 777 programs the direction of technology transf was predominantly from Boeing to its Japanese partners. This took sever forms, including data exchange and engineer training in the use of advanc computer design techniques. Boeing limited the transfer of its critical tec nologies by keeping to itself the design and manufacture of the most sensiti parts of the airframe as well as all the systems integration activities. Boei also implemented management systems that allow engineering data exchan to be managed on a "need-to-know" basis. Some technology also flows to Bo ing from Japanese companies, particularly approaches to manufacturing tec nology and processes.

In addition to the 767 and 777 partnerships, Boeing collaborated with t Japanese heavies on preliminary design and market definition work for a pr posed 150-seat transport—the 7J7-YXX program. This program contemplat significant Japanese equity participation and interaction in areas such as ma keting that the 767 and 777 partnerships did not encompass. Although t Japanese government still supports work related to the YXX, program laun has been put on hold.

The Boeing-Japan relationship appears to have delivered significant ben fits to both sides that roughly parallel their likely initial motivations. In add tion to aircraft sales in the Japanese market, the program partnerships ha allowed Boeing to spread a significant part of the program financing load. this point, the Japanese heavies have not entered partnerships with the oth two major airframe manufacturers, and have not emerged as a significant co petitive threat to Boeing. Boeing has also gained access to competitively price high-quality components.

For the Japanese heavies, the Boeing alliance has delivered technology a know-how, a significant stream of long-term business, relatively low-risk a cess to global aircraft markets, and government support in developing the technology and manufacturing bases. The Japanese participants have also some rough spots along the way. For example, exchange rate shifts during t 1980s and more recently, as well as the current market downturn, have ma apparent some of the liabilities associated with risk sharing.

Perhaps most importantly, the Japanese heavies have developed a worl class manufacturing infrastructure and technology base for aircraft structur This capability—largely built in conjunction with their work on Boeing pr grams—has implications for U.S. structures suppliers.

## Japanese Capabilities in Structures Manufacture and Implications for U.S. Suppliers

As described above, a major focus of Japanese industry in the production commercial transports is in the area of structures, particularly supplying Boei on the 767 and 777 programs. Figure 3-1 shows the global players in this ar

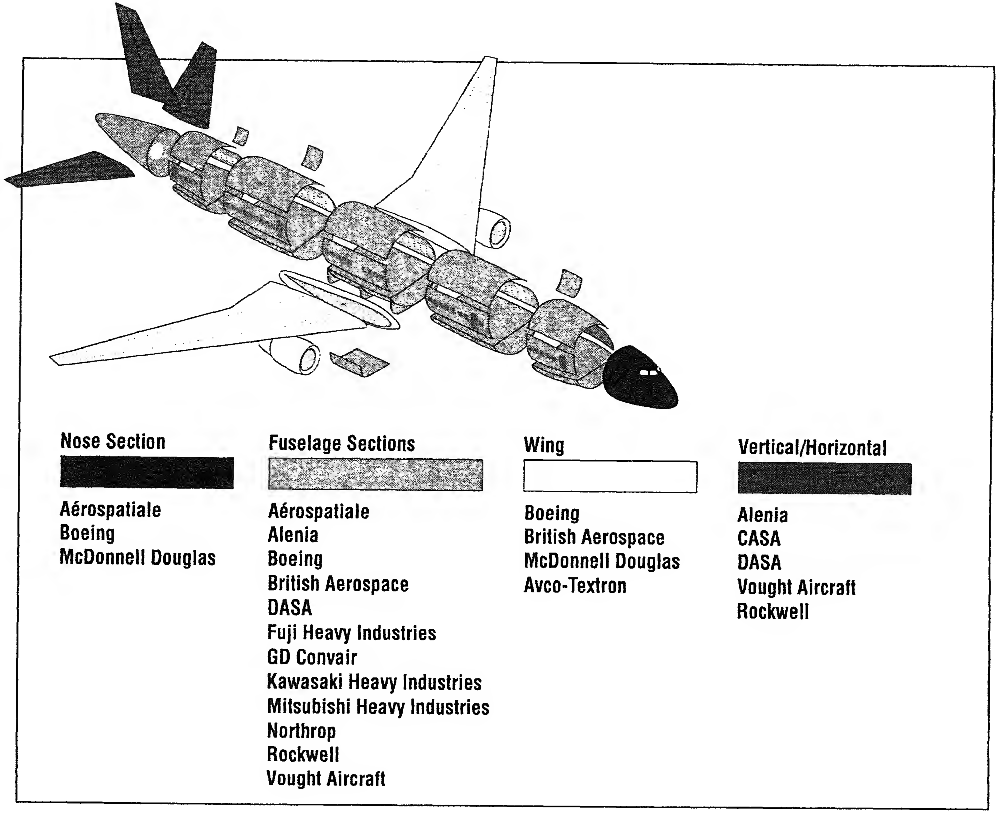


**FIGURE 3-1** Commercial airframe manufacturers. SOURCE: National Research Council Working Group on U.S.-Japan Technology in Transport Aircraft.

manufactured. The figure is not exhaustive, and it focuses on structure su ers for large commercial transports—particularly wide bodies. The airfr "primes" tend to retain manufacture of the wing (excluding control surfa and the nose section, the latter primarily because of its importance integration activities as the "brain" of the aircraft.[3]

The basic manufacturing process for fuselage parts involves consider subassembly. Premium aluminum skins are attached to aluminum "string in order to create skin panel subassemblies. These panels are then attache each other with large fuselage frames to form larger fuselage segment su semblies, a complementary set of which is fitted together to form a ho "barrel" section assembly. The barrels are then either "stuffed" with subsys (i.e., electronics, hydraulic, and environmental systems), before being joine joined into larger sections before being stuffed.

Various considerations, such as transportation, affect the manufactu process. In the case of Airbus, for example, the fuselage sections manufact by member companies are stuffed before being shipped to Toulouse, Fra where they are joined together. This is similar to the process for some military programs such as the F/A-18, in which Northrop stuffs and tests tions before shipping them to McDonnell Douglas. In the case of the Bo 767 and 777, the Japanese heavies ship the fuselage panels to Boeing, as N rop, Rockwell, and Vought do for the 747, and Boeing assembles and stuff sections.

A number of factors—such as capital availability—influence the intro tion of new technology into these processes, and some companies are more gressive than others in applying new technology. The committee was very pressed with the technology level and breadth of the structures manufactu capability possessed by the Japanese heavies. *Perhaps the most striking as of this capability is the advances the heavies have made in combining t nologies transferred from the United States with the world-class manufactu practices widely followed in other Japanese industries to create new pro technologies.*

This is apparent in Japanese innovations in the skin panel process. Fi 3-2 shows estimated Japanese technical milestones in airframe structures. S of the technologies, such as CATIA[4] computer-aided design software (C were purchased by the Japanese heavies or were transferred from the U States through commercial and military programs. For example, by integra the CATIA data base, which contains the hole locations for all variation stringers used on the 777, with an automated drill, the heavies have wo with their machine tool suppliers and/or divisions to develop an automated versal stringer drill station. Different stringer variations can all be drille this station by reprogramming, thereby eliminating the need for special

[3] This situation is evolving. For example, Fuji is supplying the wing center section for the 77

[4] CATIA (computer-aided, three-dimensional, interactive application) was first develope Dassault and later improved by IBM and Boeing.

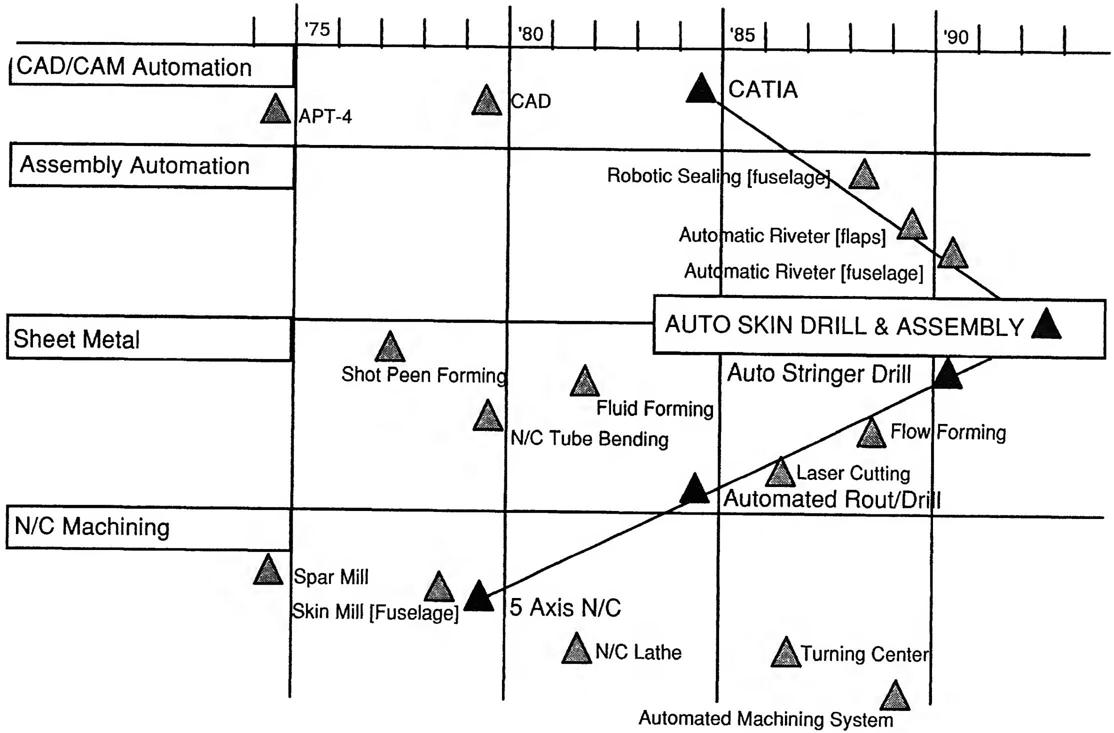


**FIGURE 3-2** Japanese airframe structure technology milestones (estimated). SOURCE: National Research Council Working Group on U.S.-Japan Technology Linkages in Transport Aircraft.

tools. The Japanese structure makers are utilizing CATIA-controlled five-
machines to automate other structures manufacturing steps, such as the ch
milling and drilling of aluminum skins. A further notable feature of Japa
structures capability is its breadth across the three heavies. For example, ce
wing section panels manufactured at Fuji use thicker aluminum skins than
fuselage panels manufactured at the other two heavies and require diffe
manufacturing processes. Taken as a whole, these manufacturing techno
improvements are good illustrations of the well-honed process of techno
improvement and deployment that exists in many of the best Japa
manufacturers. Robotics and other new machinery are developed and depl
by the heavies as part of a system that maximizes the impact of new techno
on the entire manufacturing process. These manufacturing practices are
known in the automobile and other mass production industries, but
application of new technology to aircraft production—which involves n
smaller production runs—is perhaps more challenging because of
difficulties of achieving scale economies. Japan's aircraft makers do not ut
technology for its own sake, but focus on process improvements that deliv
competitive advantage in terms of cost and quality. Although the basic pro
for improving and combining technologies, as well as some of the constit
technologies, already existed in Japan and had been applied and prove
other industries, several of the key manufacturing capabilities were transfe
from the United States.

What are the implications for U.S. structures makers, who are challen
by pressures on the defense sides of their businesses as well as the globaliza
of commercial structures procurement? First, it is necessary for American c
panies to stay abreast of developments in Japan and elsewhere. It is usually
difficult for Americans to at least tour the factories of the Japanese heavies
see their manufacturing processes. Second, American companies must be
gressive in seeking to transfer Japanese technologies back to their operati
While companies such as Northrop, Vought, and Rockwell must focus t
business strategies on future programs, they must also invest in new techn
gies and related equipment to remain competitive.

The Japanese example also shows that the challenges facing the Amer
structures suppliers go beyond the imperative of monitoring and learning
cific manufacturing innovations from Japanese competitors. In order to im
ment world-class manufacturing solutions that require large capital investm
on the order of what the Japanese heavies have made, a significant busi
base is required. This can come only from participation in new progr
which is problematic for U.S. suppliers. Because American primes feel
procurement from Japanese and other foreign suppliers is a critical elemen
enabling sales in these markets (in some cases through formal offset requ
ments, or through informal signals and pressure in the case of Japan),
structures suppliers must be particularly competitive in price, quality, and

livery performance to match the Japanese heavies or other international suppliers.

### Linkages in Military Airframes

Perhaps the most extensive U.S.-Japan technology linkages in aircraft manufacturing and—more recently—in design have occurred in military programs. Licensed production, coproduction, and codevelopment of military aircraft undertaken in the context of the U.S.-Japan security alliance have resulted in a significant transfer of U.S. technology to Japan. The two most important U.S.-Japan military aircraft linkages in the recent past have been licensed production of McDonnell Douglas's F-15 and codevelopment of the FS-X.

Japanese companies had assembled the North American F-86 in the 1950s, and had produced the Lockheed F-104 and the McDonnell Douglas F-4 under license in the 1960s and 1970s. Japanese licensed production of the F-15 beginning around 1980 was an important step in the evolution of Japan's aircraft industry and U.S.-Japan defense technology relations. Although there were early national security concerns in the U.S. Department of Defense (DOD) over the transfer of advanced technology, the broad U.S. strategic and political rationale for Japanese production—primarily a greater contribution to regional security from a more militarily capable Japan—prevailed without a great deal of contention in the U.S. government.

The United States provided technologies and data necessary for Japanese production of the F-15, with the exception of a number of items such as design data, radar, electronic countermeasures, software, and source codes classified as "nonreleasable." The extent of this "black boxing" was greater than in the F-4 program and provided a motivation for Japanese industry to pursue the independent Japanese development of the country's next fighter in the mid-1980s. Still, the technology transfer was substantial in terms of quantity, and some argue that the level of technology transferred through F-15 licensed production was significantly higher than in previous bilateral programs.[5]

Soon after the launch of F-15 production, the Japan Defense Agency (JDA), ASDF, and Japanese industry began considering options for replacing the domestically-developed F-1 fighter. Industry and some elements in the government began the process with a presumption in favor of a domestically-developed fighter. Increasing domestic content, gaining greater managerial control over the program than was possible in a licensed production arrangement, and controlling costs were all considerations. Another important factor was an underlying sense that Japan's position in the aircraft industry was fragile and that

[5]"The initial list of technical data to be made available to the Japanese in the F-15 program, for example, consisted of 21 pages listing more than 300 items that in turn consisted of everything from single drawings and rolls of microfilm to magnetic tapes and boxes of microfiche." Michael W.

passing up domestic development would consign Japan to a follower r
forever.[6]

During 1986, by which time the momentum in Japan for domestic de
opment had become quite strong, DOD began a more aggressive push for
FS-X to be based on an existing U.S. design. This resulted in an agreemen
"codevelop" an FS-X based on the design of the General Dynamics F-16. Fr
the start, the two countries conceived codevelopment differently, making it
attractive political solution but ensuring problems later. The Japanese assur
that a Japanese company would manage the process of developing an indi
nous aircraft, with selected foreign technologies incorporated as necessary. T
U.S. conceived the joint improvement of an existing aircraft, with a priority
ensuring "flowback" of Japanese technology based on know-how transferred
the United States.

A U.S.-Japan memorandum of understanding (MOU) on FS-X codevel
ment was signed in late 1988, but congressional concerns were raised dur
confirmation hearings of Bush administration officials in early 1989. Cont
tious debate over the agreement continued through the spring of that year, w
opponents arguing that F-16 technology transfers would contribute to Japan
competitiveness in commercial and military aircraft, that "off-the-shelf" Ja
nese procurement of F-16s would cut the huge U.S. trade deficit with Ja
while addressing Japan's security needs more economically, and that Japan
technical capabilities were not high enough for the flowback provisions to
liver many benefits to the United States. U.S. proponents of FS-X codevel
ment argued that significant U.S. participation in the FS-X program was be
than none at all, that Japanese procurement of unmodified F-16s was not a r
istic scenario, and that flowback would bring considerable benefits.

In the end, congressional opponents were not able to stop the FS-X ag
ment, but were able to force DOD to gain a "clarification" of several key poi
First, the Japanese explicitly committed to a 40 percent U.S. work share dur
the development phase and to providing access to Japanese-developed te
nologies. Second, the denial of several key F-16 technologies—including co
puter source codes, software for the fly-by-wire flight control system, and o
avionics software—was made explicit.

The clarification exercise threw into sharp relief the contrast between
contentious divisions over Japan policy in the United States and the much m
united front—albeit with some bureaucratic infighting—that Japan present
the United States in bilateral negotiations. In addition, the contention
heightened resentment on both sides. Many Japanese opinion leaders, in p
ticular, resent codevelopment as having been forced on Japan by the Un
States.

The development phase is now nearing completion, and first flight is p
jected for September 1995. Prospects for actual procurement are still uncert

[6]Ibid., p. 138.

If the FS-X goes into production, negotiation of a U.S.-Japan production MOU could be complicated by lingering disagreements over classifying derived and nonderived technologies, and U.S. work share.

In assessing the impact of U.S.-Japan collaboration in military programs on the technological capability of Japan's aircraft industry, analysts present a mixed picture. There is general agreement that Japanese companies receiving technology through F-15 licensed production were in a better position to supply the subsequent FS-X program. Impacts on the commercial side are less clear. At the supplier level, although a large number of Japanese suppliers make similar components for the F-15 and for the Boeing 777, many of these companies were supplying Boeing programs prior to the 777.[7] Still, the importance of military work (which accounted for more than 73 percent of Japan's total aircraft industrial output in 1990) for Japan's aircraft manufacturing and technological capabilities should not be underestimated. For example, Ishikawajima-Harima Heavy Industries (IHI) developed the capability to manufacture the long shafts for aircraft engines through the F100 program (described below in the section on engine linkages) and has evolved into a global center of excellence for this component. In addition to supporting specific dual-use technologies, Japanese military procurement supports equipment spending and engineering employment that are available for utilization on the commercial side.

At the prime level, analysts have pointed out that the FS-X program is structured to develop systems integration skills—a major missing piece of the puzzle for Japan's overall capability in aircraft. Although source codes and other critical items were not transferred, the considerable modification of the F-16 necessitated the transfer of design and systems integration technology from the United States to Japan—a first in bilateral military programs. The extent to which the Japanese will be able to capitalize on this technology in the future—in military as well as commercial aircraft development—is still an open question. There is, however, no question that it is a help.

There is also considerable disagreement about the value of Japanese technology developed through the FS-X program to which U.S. industry will have access to (either as flowback or through licensing). According to some reports, Lockheed (which purchased the Fort Worth fighter division from General Dynamics in 1992) has found the flowback of composite wing technology from Mitsubishi to be useful.[8] At this point, however, data are not being disseminated widely to U.S. industry, and some experts assert that a more systematic effort is needed to assess the value of FS-X technology flowback.

In the area of composites, the committee saw an interesting contrast between U.S. and Japanese systems of civil-military aircraft technology integra-

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[7]U.S. General Accounting Office, "Technology Transfer: Japanese Firms Involved in F-15 Coproduction and Civil Aircraft Programs," GAO/NSIAD-92-178, June 1992.

[8]Alan S. Brown, "What Can Japan Teach the U.S. About Composites," *Aerospace America*, July 1993, pp. 36-40.

tion. These differences have significant implications for U.S.-Japan linkag
a critical area of future aircraft technology development.

## COMPOSITES

### Japanese Capabilities and U.S.-Japan Linkages in Composites

As described above, most aircraft structures are made of aluminum
have been for more than fifty years. U.S. companies, most notably Alcoa
leaders in producing the high quality aluminum used in aircraft and aeros
applications, holding more than 80 percent of the world commercial tran
market excluding the former Soviet Union and China.

Although the U.S. position in aluminum is strong—a new alloy devel
by Alcoa has been specified for use on the Boeing 777—composite mate
have been gradually incorporated into airframe structures over the past
decades. They possess several properties—mainly higher specific strength
lower weight at high temperature—that make them potentially superi
aluminum as the primary material for aircraft structures.

Despite their desirable properties, composite structures present dif
manufacturing and design challenges. One of the primary barriers to incre
use of composites in commercial transports is manufacturing cost.[9] Curre
the carbon fiber-based thermoset composites that constitute the bulk o
composite materials used in commercial aircraft are too expensive to dis
aluminum on a large scale. Yet despite the cost, airframe makers are convi
that the experience gained working with composites will bring costs down
constitutes a long-term investment in a critical capability.

There are two main areas of competitive activity in composites—fab
ing structures and manufacturing basic materials. In fabrication, U.S. co
nies—including Boeing, McDonnell Douglas and others—have impre
capabilities on both the military and the commercial sides. The Japanese h
ies possess superior capabilities in this area as well. They already supply
posite structures such as tail cones and doors to both U.S. commercial airf
primes. In addition, MHI has developed through various programs culmin
in the FS-X the capability to manufacture an entire composite wing in
piece through a process called "cocuring." The Japanese heavies have inv
extensively in superior equipment (five-axis lay-up machines and autocl
for fabricating composite structures, and several companies have impre
R&D programs attacking key composites manufacturing issues. This in

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[9]From the standpoint of an airframe manufacturer, the calculation is primarily one of pri
performance. Testing new materials to ensure durability over the life of the aircraft is time cons
and expensive, but if the material performs and saves weight, and if its manufacturing costs do no
its price, the airframe manufacterer will generally bear this expense.

ment and R&D activity indicate the importance that the Japanese aircraft industry places on developing world-class composites capabilities.

In the manufacture of basic composite materials—particularly carbon fiber—the Japanese position is even stronger than in fabrication. The current U.S.-Japan technological and competitive position in this area illustrates a number of the challenges the United States faces as DOD requirements become less important for driving the development and application of a range of technologies, particularly those relevant to the aircraft industry.

In the United States, DOD and the National Aeronautics and Space Administration (NASA) have provided major support over the years to develop a range of new advanced materials, and U.S. basic research at universities, and at national and industrial laboratories, is unmatched. Composites using carbon fiber have come furthest in their applicability, and a number of companies increased their production capacity in the late 1980s in anticipation of a large DOD demand base. However, since the late 1980s, the anticipated defense market has not materialized and a number of the U.S. manufacturers of carbon fiber have shut down or been sold to foreign investors.

Some of the leading producers of carbon fiber in the world are Japanese companies such as Toray, Toho, and Mitsubishi Rayon, which began making the materials to incorporate into sporting goods and other consumer products. This large manufacturing base has allowed them to focus on competing in the aircraft market with a longer-term view on the basis of competitive manufacturing costs. In addition to Toray's success in becoming the sole qualified supplier of carbon fiber and resin for the Boeing 777 composite tail, it has recently purchased the leading European manufacturer of carbon fiber. Toray did license a U.S. firm with its carbon fiber technology several years ago, but this did not result in establishing a price-competitive U.S. capability. A new Toray facility to be built near Seattle will weave and shape fibers made in Japan to Boeing specifications. Toray is interested in other aerospace applications, and in 1992 it purchased Composite Horizons, a small spin-off of Hughes Aircraft that manufactures composites for satellites.

Toray's competitive strategy and the nature of its alliances with U.S. companies highlight concerns about reciprocal technology transfer and market access in the field of advanced materials. For example, Toray has free access to the U.S. market, and is not restricted from working closely with Boeing and other lead users to hone its capabilities. It is also free to make manufacturing investments and high-technology acquisitions such as Composite Horizons. However, the committee heard that some U.S. materials makers have found it difficult to enter the Japanese market without forming an alliance with a Japanese company, often a potential competitor (although it is not a legal requirement). Such joint ventures generally do not provide opportunities for the U.S. partners to establish direct interactions with sophisticated customers in Japan who drive future development of components. The situation is evolving as U.S.

companies develop a variety of mechanisms to access growing markets for vanced materials in Japan and elsewhere.[10]

In contrast to the excellent but fragmented efforts of the United State advanced materials, the Japanese approach of industry-government collab tion in this field leverages Japanese industry's existing strength in mass duced materials and incorporates focused government-funded research grams to target emerging applications. Basic research is conducted at a m lower level than in the United States, while basic research in U.S. univers is readily accessible to Japanese companies.[11] Government-industry technol development programs tend to focus on processes that optimize the utilit existing fibers and materials that are widely available. Aircraft structures propulsion are major applications targeted in these programs. Commercial military-oriented investments are mutually supportive.

It is clear that the Japanese government and Japanese industry see ma als development as an important entry point to participation in future inte tional aircraft programs. In order for the United States to reap the econo rewards of the substantial R&D funds expended in this area, both governn and industry need to face up to several new challenges. For government, fu ing R&D on materials that must "buy their way onto the airplane" will req different criteria and research mechanisms than the "performance at any pr imperatives of military-driven technology development. For U.S. industry will be necessary to build better collaboration between materials suppliers users than has been exhibited on the commercial side up to now. In addit the challenge facing U.S. makers of advanced materials in accessing the J nese market remains considerable.

While Japan's advanced materials capability has progressed to the p where Toray is supplying the material for the largest composite primary st ture to date made by the U.S. aircraft industry, cuts in defense demand have to severe distress for U.S. manufacturers of carbon fiber, causing several to the business.

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[10]Du Pont has opened a laboratory in Europe to gain access to advanced materials users there has formed an alliance to improve access to Japan and Asia-Pacific markets. See Michael Mecham, Pont Seeks Partners at Euro-Composite Center," *Aviation Week and Space Technology*, Octobe 1992, pp. 64-65; and "Du Pont, Mitsui Form Asia Region Composites Alliance," *Chemical Engineering News*, December 13, 1993, p. 12.

[11]According to a 1991 report by an expert panel examining Japan's composites technology the auspices of the Japan Technology Evaluation Center (JTEC), there is "little research effort fundamentals which determine the materials system selection or in the fundamentals of comp behavior. The Japanese were familiar with the systems selected for development in the United State the rest of the world." R. Judd Diefendorf, Salvatore J. Grisaffe, William B. Hillig, John H. Perep R. Byron Pipes, and James E. Sheehan, *JTEC Panel Report on Advanced Composites in J* (Baltimore, Md.: Loyola College, 1991), p. 13.

## ENGINES

Because jet propulsion is the key enabling technology underlying commercial and military aviation as we know it today, the engine industry plays a special role in the aircraft supplier base. Both U.S. engine primes—GE Aircraft Engines and the Pratt & Whitney division of United Technologies—have extensive, long-standing technology linkages with Japan. The global context is important. Figure 3-3 illustrates the complex web of current international alliances in the commercial and military jet engine businesses. Both companies have been involved with Japan in military, commercial, and Japanese government-sponsored R&D programs.

GE has focused its engine collaboration in Japan with IHI,[12] while IHI—as the leading Japanese company in aeroengines—collaborates with Pratt & Whitney and Rolls Royce as well as GE. GE-IHI linkages have a longer history on the military side. GE was involved with the first Japanese postwar military aircraft program starting in 1953, with the J47 engine for the Japanese version of the F-86 fighter. Over the next several decades, GE's J79 engine was chosen to power the Japanese versions of the F-104 and F-4. GE's relationships with Japan during this period involved sending kits to IHI for assembly and test, with some components manufactured by IHI. More recently, GE's F110 engine was selected as the engine for the FS-X, and IHI is collaborating with GE in developing interfaces for the aircraft.

GE's collaboration with IHI in the development of a large commercial engine is fairly recent, having only begun with the GE90. The GE90 is the first of what GE hopes to be a new family of large engines to power the next generation of commercial transports. When the program was conceived in the late 1980s, it was decided that a global program structured around GE's existing international relationships would best leverage resources. In addition to IHI, which has an 8 percent share in the program, Snecma holds a 25 percent share and Fiat 8 percent. Each partner is responsible for designing and developing its specific part of the engine. IHI is responsible for several stages of turbine disks for the low-pressure turbine, the blades in those disks, and the long shaft that goes between the low-pressure turbine and the fan. Further, program participation requires partners to make considerable capital investments in testing and manufacturing infrastructure. IHI has proceeded to make the necessary investment to build a test cell.

The GE90 is currently undergoing testing and certification, and is scheduled to enter service in 1995. Although it is not possible to assess the bottom-line impacts on the participants, GE is pleased with the partnership and with IHI's contribution and performance to this point. The disks and turbine blades were impeccably designed and manufactured the first time around. GE has also learned some useful lessons from IHI, particularly from the rapid prototyping that IHI did for the turbine blade casting.

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[12]GE's relationships with IHI and Toshiba date back to the pre-World War II period.

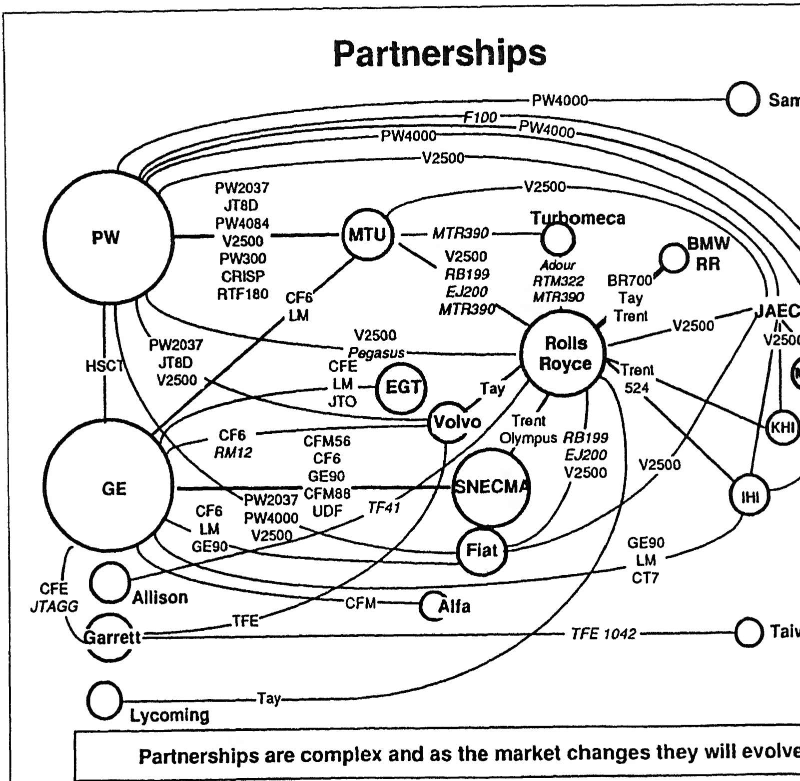


**FIGURE 3-3** International partnerships. SOURCE: GE Aircraft Engines.

GE and IHI collaborate in several other areas. The HYPR program cussed below. In addition, in July 1992 the two companies signed a broa to jointly develop selected technologies. GE initiated the MOU because ized that opportunities to learn from IHI will increasingly arise as IHI d its own technologies through independent efforts and as part of Japane ernment-sponsored programs. GE would provide some of its know- exchange. The MOU provides an umbrella structure for identifying and ing specific opportunities.

GE's formal technology transfer procedures are followed on each program undertaken with IHI (or any other partner). First, the busine that wishes to transfer technology applies to a senior management tech council, which approves or disapproves specific transfers in light of the strategic position of GE Aircraft Engines. If the technology transfer is ap

export license, and to DOD and Department of Commerce as necessary. GE's licensed production contracts with IHI—going back to the J47—include flowback provisions in which GE will obtain improvements that IHI makes in its technology.

Pratt & Whitney's (P&W) technology linkages with Japan are also extensive, and have included a slightly wider range of mechanisms and partners than GE's. P&W established a relationship with MHI in the 1930s that was interrupted by World War II, and it has also linked with IHI and KHI. P&W's motivations for establishing technology linkages with Japan are similar to GE's—to gain market access in military engines, to gain access to high-quality components, to spread development burdens, and—increasingly—to gain access to Japan's growing technological capabilities.

In 1978, the F100 engine was selected to be used on Japan's F-15s. This relationship has evolved from complete engines delivered to IHI, to knockdown kits, to licensed production. Some of the materials and the electronic engine controls were held back by DOD, but IHI now manufactures about 75 percent of the engine by dollar value. IHI continues to incorporate improvements that P&W developed for the U.S. version of the F100. P&W launched an earlier and less extensive military licensed production agreement in 1971 with MHI covering the JT8D-9 engine for Japan's C-1 military transport. In 1984, MHI became a 2.8 percent risk-sharing partner in the manufacture of a derivative product, the 20,000-pound JT8D-200.

P&W has two Japanese partners in the PW4000 program, a large engine with several derivatives that powers some versions of the Boeing 747, 767, 777, and the Airbus A300, A310, and A330 aircraft. The engine was originally developed in the early 1980s. Kawasaki became a 1 percent risk-sharing partner in 1985, and has continued at that level since then. MHI signed on as a 1 percent risk-sharing partner in the PW4000 program in 1989, and its participation grew to 5 percent in 1991 and 10 percent in 1993. MHI is responsible for manufacturing various turbine blades and vanes, turbine and compressor disks, active clearance control components, and combustion chambers. The increase in MHI's share since 1989 has come about as a result of mutual satisfaction with the relationship and a desire to expand it.

In addition to risk-sharing agreements with MHI and KHI in commercial engines, P&W has a long-term sourcing agreement with IHI to produce the long shaft connecting the high- and low-pressure turbines for the JT9D, PW2000, and PW4000. IHI will manufacture all of Pratt & Whitney's commercial long shafts. Utilizing and improving upon the process transferred in connection with the F100 program, IHI has become a world-class center for the production of long shafts of more than 8 feet. As mentioned earlier, IHI will be manufacturing the long shaft for the GE90, and it manufactures all of Rolls Royce's shafts as well. This specialization is not uncommon in the engine business: Fiat dominates the manufacture of gear boxes, and Volvo is strong in casings. Although IHI's dominance in shafts raises issues of dependence and

possible supply disruption, the engine primes manage this dependence by r
taining some capability of their own. The focused manufacturing approacl
ries significant benefits in terms of cost and quality.

Pratt & Whitney is also a major partner in International Aero En
(IAE), a global program that developed and is now marketing the V250
gine. This program marked the first time the Japanese participated in a r
engine development program. Pratt & Whitney and Rolls Royce are the
partners—both hold 30 percent shares in the program. Germany's MTU
11 percent and Fiat 6 percent. Japan Aero Engine Company (JAEC) hol
percent of IAE, and is itself a joint venture of IHI (with 60 percent of JA
Kawasaki (25 percent) and MHI (15 percent). JAEC is responsible for th
and the low-pressure compressor.

All of the non-U.S. members of IAE received support from their go
ments for their participation. JAEC has received annual payments of $20
lion to $25 million from the Ministry of International Trade and Ind
(MITI) since the start of the abortive FJR710 program in the early 1970s
this support has continued through V2500 development, covering rough
percent of JAEC's development costs, 66 percent of testing costs, and 50
cent of the production tooling and nonrecurring startup costs.[1] Repayment
interest of these success-conditional loans is slated to commence when the
gram breaks even. The V2500 faces tough competition from the CFM Int
tional CFM56, but appears to be gaining greater market acceptance over ti

Both GE and P&W participate in the Japanese Supersonic/Hypersonic
pulsion Technology Program (JSPTP or HYPR), which was launched by
in 1989 as a $200 million, 8-year program (since extended to 10 years)
ultimate goal of the program is the development of a scale prototype t
ramjet, Mach 5 methane-fueled engine. The program is administered by
through its Agency of Industrial Science and Technology and the quasi
ernmental New Energy and Industrial Technology Development Organizat

The Japanese partners—IHI, KHI, and MHI—receive 75 percent c
funding and take the lead on technology development and design. HY
significant in that it is one of the first of Japan's national R&D projects to
template international participation from the outset as an integral feature c
program. The foreign participants—who receive 25 percent of the funding
Pratt & Whitney, GE, Rolls Royce, and Snecma. The formal agreemen
tween MITI and the foreign engine companies was signed in early 1991
process of negotiating this participation was somewhat long and complex
major stumbling block being the treatment of intellectual property generat
the project. The four foreign companies joined together to negotiate with
as a united front. This process led to an agreement and a change in Ja
laws governing intellectual property rights in government-sponsored R&D

[1]David C. Mowery, Alliance Politics and Economics: Multinational Joint Ve

From the point of view of GE and Pratt & Whitney, the main motivation for participating is that taking a role in the Japanese program is preferable to a major supersonic/hypersonic engine program going forward without U.S. involvement. By participating, GE and Pratt & Whitney gain insights into the basic design decisions and capabilities of the Japanese members of HYPR. Thanks to MITI funding, participation is not costly for the foreign firms. The U.S. engine makers believe that as a major terminus for flights of the next-generation supersonic transport, Japan will inevitably be involved in its development. As a separate initiative, GE and P&W are collaborating on NASA-funded research on high-speed civil transport propulsion targeting an engine in the Mach 2-2.5 range.

The basic interaction between foreign and Japanese companies in HYPR is participation in design review and analysis in designated program areas. Since the program is currently in its fourth year and will probably run for ten, the impacts and implications cannot be assessed precisely. The eventual impact will depend a great deal on the timing and mechanism for developing propulsion for the next-generation supersonic transport. While foreign participation allows the major international players to keep tabs on Japan's approach, the Japanese participants gain design insights from foreign coaching. Also, international participation in HYPR has itself served to give credibility to Japanese efforts to play a significant role in international advanced engine programs and to other Japanese government efforts to organize international R&D collaboration.

The Japanese government also funds several other programs that have implications for future aircraft propulsion systems. The one that is most closely linked to HYPR is the research program on high-performance materials organized under MITI's "Jisedai" or Next-Generation Technology Development funding pool. The program began in 1989 and is scheduled to run through 1996. In addition to these ongoing R&D programs, the Japanese government—mainly MITI and the Technology Research and Development Institute—is conducting a number of feasibility studies aimed at significantly upgrading Japan's engine testing facilities over the next decade. JDA is also making funds available for a high-altitude test facility in Hokkaido.

Japanese aircraft engine makers have effectively leveraged private and public resources in international alliances and public R&D projects to improve and deepen their technological and manufacturing capabilities. Individually or as a group, Japanese companies are well positioned to continue to participate in international engine development programs at increased levels of technical and manufacturing responsibility. Japan's government technology programs and corporate strategies are aimed at playing a major role, if not one of world leadership, in advanced propulsion materials and other targeted critical technologies.

## AVIONICS

Avionics is another critical part of modern transport aircraft. Advanc navigation and flight control systems have the potential to further reduc cost and increase the safety of air travel. Commercial avionics is a $3 b per year business worldwide. The two dominant players are American co nies—the Collins division of Rockwell International and Honeywell. Japan technology linkages are fairly extensive in this sector and take se characteristic forms depending on the market.

On the commercial side, U.S.-Japan linkages have been driven by ch in the nature of innovation in avionics hardware over the past 15 years. the mid- or late 1970s, the bulk of hardware innovations incorporated commercial avionics came from military electronics developments. Inc ingly, however, avionics systems incorporate component technologies firs veloped for consumer electronics and high-demand computer applica Over the past several decades, as Japanese companies achieved and exte their dominance in consumer electronics and gained strong positions in se areas of the semiconductor industry, Japan has become the major sourc these hardware innovations. Although standard components can be inc rated into avionics black boxes in some areas, in others the perforn requirements necessary for an avionics application go so far beyond the bilities of the standard component that an extensive modification effort is essary. This is the fundamental dynamic driving U.S.-Japan techn linkages in commercial avionics today.

The best current example of this trend is flat panel displays. The l crystal display (LCD) technology that was invented in the United States i late 1960s has been nurtured and improved by a number of Japanese comp for more than 20 years. Passive and active matrix LCDs are now the dom technology of flat panel displays in rapidly growing markets such as po computers and hand-held television sets. Japanese companies such as S and Hosiden are the leaders in this technology, and Japan currently holds than 90 percent of the flat panel display market. Several small U.S. firm velop and manufacture some displays for military and other niche applica but they do not have the capital to invest in the necessary manufacturin pability for large-scale production.

In developing the next-generation avionics systems that will be install the Boeing 777, both Collins and Honeywell clearly saw the advanta mainly space and weight savings—of replacing cathode-ray tube displays flat panels. Although both Collins and Honeywell briefly considered oth ternatives, it soon became clear that the Japanese companies that curr dominate the world market were the best source of a cost-efficient sol Collins teamed with Sharp and Toshiba, and Honeywell worked with Hosi

Whereas the necessity for acquiring this high value-added componen clear and compelling on the U.S. side, the Japanese display makers had

convinced to take up the task—avionics is not a large market compared to laptop computers, and a significant commitment of engineering resources would be required. However, there were also compelling advantages for the Japanese display makers, such as the opportunity to lock in a long-term, profitable stream of business and to develop new capabilities for their displays.

Perhaps the most important benefits for the Japanese firms were the interrelated benefits of learning about technology and business methodology in a very high-image market. Although the American firms were very careful to employ the Boeing-like strategy of keeping these key suppliers limited to display development, technology transfer was necessary to enable the Japanese companies to solve the unique problems arising in the development of displays that meet avionics needs.

In terms of the immediate business and technical objectives, U.S.-Japan linkages in commercial avionics usually achieve their goals and bring the expected benefits to both sides. The U.S. integrator gains a reliable supply of high value-added components or subassemblies at a reasonable price, which helps add value for the end user. The Japanese partner gains steady business, technology, and learning benefits that can be applied to its core business or serve as a basis for further expansion in aircraft markets. For example, many new aircraft will incorporate flat panel displays in the cabin as part of passenger entertainment and communications systems as well as in avionics. The Japanese display makers can directly apply knowledge of the business methodologies of airframe makers and airlines to their efforts to market displays for these systems.

The downside of the flat panel display relationship was felt when the small American manufacturers filed an antidumping suit against the Japanese, and the International Trade Commission placed punitive tariffs on Japanese imports. Collins and Honeywell have been hurt by these duties, but would not consider transferring manufacturing out of the United States in response, as have several U.S. makers of laptop computers.

There are also extensive U.S.-Japan technology linkages in military avionics, but these are of a completely different character from the commercial supplier alliances. In order to gain access to the JDA market, U.S. avionics makers must often license production or enter other collaborative relationships with Japanese companies like Mitsubishi Electric or Japan Aviation Electronics. This often happens as part of a licensed production program such as the F-15.

In all of these relationships, the transfer of technology is almost exclusively from the United States to Japan. In the commercial field, the United States receives products in return for technology; and on the military side, market access.

What are the competitive issues posed by U.S.-Japan linkages in avionics? Is there a long-term danger that Japanese companies will become full-line avionics integrators? American avionics industry leaders recognize the consider-

panies, and realize that they often deal from a position of weakness in se
to gain access to component technologies. A high percentage of the value
in current avionics systems consists of Japanese components, and the pe
age will very likely continue to rise. The avionics market might be app
for the Japanese as a high-profile industrial market with some potenti
driving technology development that could be applied to core businesses.
the Japanese are very aggressive in developing nonavionics electronic sy
for aircraft (entertainment systems and satellite communications), as w
mass market applications of technologies that are closely related to avi
such as automotive applications of GPS (already being marketed in J
Collins and Honeywell are interested in some of these markets, but they a
well entrenched.

However, while Japanese companies are capable of moving up the av
food chain, there are significant capabilities that they do not yet posses
there are few signs that Japanese industry or government is aggressively
oping them. For example, the software and systems integration skills th
needed to develop the current generation of avionics is beyond current Jap
experience. Although the value of Japanese components is high, U.S. av
companies do not anticipate a short-term challenge from Japan in the in
tion segment. They would prefer to have more leverage as they incor
Japanese technologies into their systems, but believe that the lack of a U.S
sumer electronics industry is the main cause of the difficulties they
experienced.

From a U.S. policy perspective, the impacts and implications are
complex. The U.S. Department of Defense and other agencies have ide
flat panel displays as a key technology for a range of industries. DOD'
vanced Research Projects Agency, the Department of Commerce's Adv
Technology Program, and Department of Energy laboratories have launc
number of technology development programs to help build competitive
capabilities in this area. Avionics companies might be obvious "lead use
these efforts, but it does not appear that any U.S. avionics companies ar
rently involved in U.S. government-sponsored efforts. As in advanced m
als, the flat panel display example illustrates that the challenges invol
planning and implementing an effective civilian technology polic
considerable.

## OTHER COMPONENTS AND SUBSYSTEMS

Modern transport aircraft incorporate a large number of subsystem
components manufactured by a variety of large and small companies. S
tems include electrical power systems, actuation systems, and landing
Each subsystem and the aircraft as a whole incorporate numerous and
components such as gears, materials, and integrated circuits. Japanese c
nies have become quite prominent in some parts of the supplier base. F

ample, most of the precision bearings needed for aircraft engines are now manufactured in either Japan or Germany. Companies in those countries built on existing strengths in bearings to eliminate the remaining American companies from this high-performance segment. Bearings—like flat panel displays—represent a field in which Japanese companies entered aerospace markets because of capability acquired in more general-purpose markets.

Japanese success in supplying dedicated aircraft components and subsystems is more uneven. Teijin Seiki—whose original business was textile equipment—has achieved a prominent position in primary actuation systems and supplies all recent Boeing programs. Teijin Seiki is also actively building other parts of its aircraft subsystem business, partly through a joint venture with Sundstrand. Other Japanese companies such as Kayaba, Shinko Electric, and Yokohama Rubber have also gained success in some subsystem and component areas.

Because of the wide variety of products and companies involved, U.S.-Japan technology linkages in aircraft subsystems and components are difficult to characterize in a general way. In contrast to expanding relationships between U.S. primes and Japanese suppliers, there appear to be few linkages between U.S. and Japanese suppliers on the commercial side. Most U.S. supplier-Japanese supplier technology linkages have been formed in the context of Japanese military programs. Particularly in cases where U.S. systems have been coproduced or produced under license in Japan, JDA and Japanese industry generally pursue licensed production of U.S. subsystems and components that embody significant technology.

The STS Corporation joint venture between Sundstrand and Teijin Seiki raises a number of the relevant technology transfer and market access issues faced by U.S. suppliers wishing to participate in the Japanese aircraft market. Sundstrand's involvement in the Japanese aircraft market began in the late 1960s with licensed production of electric power generating system constant-speed drives by Teijin Seiki for Japanese military programs. This licensing arrangement evolved into the formation of a 50-50 joint venture company called STS Corporation about a decade ago.

Improved market access was Sundstrand's primary motivation, and it has seen tangible benefits in this regard. The original target was the military market, and a significant proportion of STS's sales still go to military programs. There appear to be market access benefits on the commercial side as well. Examples include STS's supply of the main fuel pump for the V2500 engine and Sundstrand's participation in the MD-12 actuation team with Teijin Seiki and Parker Hannifin.

As the venture markets Sundstrand's more mature technologies, the transfer of technology through the joint venture has been predominantly from Sundstrand to STS—while Teijin Seiki provides the personnel to staff the venture. STS participation in SJAC collaborative R&D programs may bring reverse technology transfer opportunities in the future.

Although the venture should be termed a success from the standpoint o strategies of the two parent companies, it is an illustration of continuing Japan technology and market access asymmetries. While Sundstrand fou prudent to team with a Japanese company in order to expand market opp nities in Japan (and even in the United States, in the case of the MD-12), are few barriers to Teijin Seiki and other Japanese subcontractors sellin rectly to Boeing and other U.S. primes.

## DISTINCTIVE FEATURES OF U.S.-JAPAN AIRCRAFT LINKAGES

### Motivations and Benefits for the United States

The committee identified a number of significant motivating factors benefits of expanding U.S.-Japan technology linkages in the aircraft indu Significantly, these benefits are more likely to be realized by U.S. comp dealing from the strongest technological and business positions—the airf and engine primes such as Boeing, Pratt & Whitney, and GE. Most of benefits revolve around the generally superior performance of Japanese panies in this field as business partners.

#### *Long-Term Commitment of Resources*

Japan as a country, as well as the individual companies involved in th dustry, is committed to a long-range strategy of aerospace growth. U.S. panies linking with Japan can be reasonably assured of their partner's mitment to invest despite the long-term payoffs typical in this industry. Th a particularly important benefit in view of the escalating costs of aircraft engine development programs.

#### *No Barriers*

Apart from the difficulties that U.S. companies may experience in ac ing Japanese companies, there appear to be no formal barriers to aerospac operation—at least at the level of U.S. prime integrators.

#### *Focus*

Japanese partners generally have an unrelenting focus on meeting pr schedules and target costs, once negotiated. They bring their notions of tinuous improvement to the program and do not hesitate to invest to const improve quality.

*Access to World-Class Manufacturing*

Japan's focus on manufacturing processes is apparent throughout their aerospace units. Much of this know-how is available to U.S. partner companies if they are willing to make the investment needed to transfer the technology back home.

*No Leakage*

In the aerospace industry today it is common for individual Japanese companies to have partnerships or close relationships with several competitive companies at the same time. This provides an opportunity for "leakage" of plans, activities, and know-how from one competitor to another. U.S. companies who have partnered with Japanese aircraft companies have not experienced this problem.

*U.S. Access to the Japanese Market*

Although Japan has no aircraft offset requirements or other formal trade barriers in aircraft, market leverage has been a major motivator of linkages on the U.S. side. Airbus has managed to sell aircraft to Japan despite an absence of significant linkages. Generally speaking, however, a presence in Japan is seen as a prerequisite for participation in the market. Boeing and McDonnell Douglas have sourced portions of airframes in Japan to enable or promote sales to the Japanese airlines. Engine makers have also followed this strategy, whereas components manufacturers have followed a pattern of joint ventures as a means of gaining access as suppliers to the market for military aircraft in Japan. U.S. companies have also found, however, that cooperative programs do not ensure sales.

## Risks for U.S. Industry and the United States

Juxtaposed to the benefits are the risks of technological collaboration with Japan. The committee identified a number of risks faced by participants in linkages and other U.S. companies.

*Enabling Competitors*

One risk faced by U.S. companies undertaking technology alliances with Japanese companies (or other foreign partners) is that technology transferred to a partner through the alliance, or developed independently thanks to the joint program revenue base, will be used by the Japanese partner to market a competing product. This can occur through military or commercial programs. At the prime airframe and engine levels, this risk has been realized by U.S. firms, but

not in relationship to Japan so far—some technologies, such as fly-by-transferred through the European F-16 coproduction program, were later by Airbus. Some U.S. suppliers, particularly in the context of military grams, have faced Japanese competition from licensing partners—the ring gyro case cited in Appendix B is one example.

*Displacement*

Another risk faced by U.S. suppliers is that they will be displaced by J nese competitors in the context of technology linkages with Japan forme other U.S. companies. This is currently occurring in the aircraft structures for example, the displacement of Northrop as a components supplier on the and 777.[2]

*Dependence and Loss of Critical Capabilities*

In some cases, Japanese strength in technologies developed in other in tries and applied to aircraft may have the effect of stifling nascent U.S. c bilities. To U.S. industry, there is a danger that capabilities critical to the fu of the industry will be completely absent in the United States, or that U.S. b research feeds development and commercialization activity that largely oc in Japan (as has happened in industries such as robotics). If the technolog critical enough, U.S. primes may find themselves in the position of havin transfer more of their own technology than they would like in order to ac Japanese capabilities. Flat panel displays and some areas of advanced mate are examples in which this risk has been realized.

*Market Access Problems*

At both the prime and the supplier levels, but particularly in the cas suppliers, formal and informal Japanese trade and investment barriers nece tate the trade of technology for market access. Often, the only viable option makes business sense to U.S. companies is a joint venture. In some cases may be a low-risk strategy. In areas where direct contact with customers pla major role in driving technology development, however, some companies found that their joint ventures constrain their relations with other Japa companies or serve to create powerful competitors.

*Technology Access Problems*

U.S. companies and the United States as a country have transferred more technology to Japan than vice versa, particularly in the aircraft indus

The United States runs the risk of forgoing significant opportunities to improve the competitiveness of its aircraft industry if the flow of technology from Japan is not increased—both through lowering Japanese barriers and through devoting more of its own resources to acquiring and assimilating the available information.

*National Security*

Particularly in military programs, there is always a risk that technology transferred overseas could come back to threaten U.S. national security; this is the rationale behind export controls. In the case of Japan, this risk has been judged to be quite low—a qualitatively higher level of technology transfer through aircraft and other military programs has been allowed for Japan than for other allies.[3]

## Evolution of Linkage Mechanisms

U.S.-Japan linkages display several characteristic features in terms of mechanisms and trends:

- For linkages formed by U.S. integrators in airframes and engines on the commercial side, interaction with Japanese companies generally begins with the establishment of a supply relationship. In the case of linkages of U.S. primes with the Japanese heavies, interaction has increased over time—often supported by Japanese government policy. Japanese companies are now or could ultimately become capable of manufacturing all the parts of modern commercial airframes and engines. In engines and airframes, the pattern may be shifting toward significant Japanese participation as partners in global programs managed by U.S. primes.
- A relatively new mechanism is foreign participation in Japanese government-sponsored R&D programs such as HYPR. The future direction of this mechanism is unclear, but in addition to true joint development of new technologies, such programs also have a component of transferring existing knowledge from foreign firms with advanced capabilities to their Japanese competitors. Although the Japanese government has launched several international R&D programs since HYPR, none has focused on aircraft specifically.
- At the prime level in military programs, the pattern has been one of U.S. technology transfer to Japan, with a dynamic of increasing Japanese responsibility and technological capability over time. The direction of U.S.-Japan military program links after the FS-X is unclear.
- Linkages at the supplier level present a mixed picture. On the military side, U.S.-Japanese supplier links often occur in conjunction with large pro-

grams and involve Japanese licensed production of the U.S. component cases where the U.S. company has a strong technological edge, these relat ships sometimes extend over several programs and even evolve into collab tion in commercial fields. In other cases, such as the mission computer and electric power generating system for the FS-X, Japanese companies have placed U.S. companies by developing independent capabilities.

## U.S. and Japanese Strengths and Weaknesses Underlying Linkages

*Japanese Strength—Manufacturing Capability and Investment Resourc*

Japanese aircraft companies have demonstrated the creativity and reso commitment necessary to apply world-class technology to aircraft product In addition to the aircraft industry itself, Japanese capabilities in areas suc composite materials and flat panel displays have been developed through vestment in manufacturing excellence aimed at other markets, and are fin increasing application in aircraft. In contrast, some U.S. companies have fo it difficult to invest in capital-intensive manufacturing processes in the Un States in recent years.

*Japanese Strength—Integrated, Supportive Policy Environment*

A Japanese policy environment encouraging international alliances transfer technology to Japan, civil-military integration in the domestic indu and cooperation between companies helps to maximize the impact of Jap technological strengths. Although the U.S. aircraft industry is dynamic, po agendas are often fragmented and government agencies sometimes wor cross-purposes.

*U.S. Strength—Systems Integration and Other Advanced Technologies*

U.S. technological excellence across a wide range of aircraft techn gies—particularly those associated with systems integration—is unmatc U.S. industry, academic, and government R&D capabilities in aeronautics, pulsion, materials, and other associated fields are the foundation for future competitiveness in the global aircraft industry. Although Japan is making forts to build wind tunnels and other necessary research infrastructure, con erable resources over a long time period will be necessary.

*U.S. Strength—Long-Term Familiarity with Needs of the Global Marke*

Particularly at the level of integrating airframes, engines, and avion U.S. companies have maintained an aggressive global marketing presence

facilitates the incorporation of customer needs into products, as well as the capabilities in safety certification necessary to sell products globally. The Japanese industry has tried to develop marketing and product support capabilities though international alliances, with some limited success.

## Outcomes and Implications of U.S.-Japan Linkages

### *Japanese Capabilities and Strategy*

Although Japan is missing some technological squares in the matrix of critical aircraft capabilities (systems integration, marketing), it currently possesses the necessary infrastructure to support an indigenous aircraft industry. Japanese companies and government are pursuing international alliances and technology development programs to fill in the missing pieces. Japan is making the necessary investments to increase its presence in the commercial aircraft market, focusing on manufacturing quality and cost leadership.

Japan has not launched an effort at the airframe or engine prime level to compete with U.S. firms; nor has it formed significant relationships with Airbus or other international players. Japan would likely become a formidable U.S. competitor if it decided to pursue either of these options, and government and industry are currently reevaluating their basic approach to the industry. In any case, Japan is a significant factor in the global aircraft industry. U.S. collaboration with Japan entails benefits and also some risks, but at this point it appears that continued cooperation is preferable to the alternatives.

### *Technology Transfer*

Technology flow through U.S.-Japan linkages in the aircraft industry has been predominantly from the United States to Japan. Although historically, more technology has flowed through military than commercial programs, commercial alliances formed over the past 10 to 15 years have also transferred technology to Japan or in some cases, stimulated independent Japanese development when they were not given access. Although it appears that DOD and U.S. companies involved in military and commercial linkages have by and large protected critical technologies while reaping significant benefits from these relationships, the impacts of the most recent and significant technology transfers (through the FS-X and extensive commercial program links) are still unclear. The security environment that justified a pattern of extensive U.S. aircraft technology transfer to Japan is rapidly changing, and there is a need to take economic considerations into account. In view of the large U.S. stakes in this industry and the rapidly expanding Japanese capabilities in many significant technologies, a more balanced flow of aircraft technology between the two countries should be key to a continuation of mutually beneficial interaction, and

should be pursued by U.S. industry and government as a strategy and a r
policy goal.

*The U.S. Supplier Base*

Although U.S. primes have by and large had good experiences in the lationships with Japan, evolving patterns of global manufacturing capal and industry restructuring—in which U.S.-Japan linkages are an importan of the context—already threaten existing parts of the U.S. supplier base may prevent the development of U.S. commercial capabilities in a numb critical, emerging areas. This situation suggests the need to reexamine manner in which technology development and related business activitie organized and funded in the United States, in order to promote more effe relationships between U.S. companies and between industry and governn as well as ensure retention of an innovative full-spectrum aerospace capab Where the technologies impart both security and economic growth, there need for more attention and coordination among various government age to ensure effective use of public support for R&D and procurement releva industry, especially the supplier companies. Failure to address these i implies continued erosion of the domestic U.S. supplier base and a concom increase in the probability of Japanese entry at the prime level as its sup base becomes more developed.

# 4

# Future Trends

## MARKETS

Over the next several decades, demand for air transport, and the aircraft necessary to carry it, should continue to grow at a relatively high rate. Boeing's forecast, for example, envisions an annual average growth in world airline passenger traffic of 5.4 percent from 1992 through 2010.[1] Such rates are somewhat lower than those prevailing over the past two decades (6.8 percent), but are still substantial. Similar trends are expected for the global air-freight market (with a 6.5 percent growth to 2010 in the Boeing forecast, compared to 8.0 percent from 1970 to 1992).

This overall growth will produce a continued increase in demand for new commercial aircraft. Boeing anticipates a global market for aircraft of $815 billion in constant 1992 dollars from 1992 to 2010 (including $204 billion in replacements and $611 billion in additional capacity).[2] McDonnell Douglas envisions a somewhat higher $1.0 trillion global market for aircraft over the same time period, representing a total of 14,072 units.[3]

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[1]Boeing Commercial Airplane Group, *Current Market Outlook: World Market Demand and Airplane Supply Requirements* (1993), p. 25.

Within this overall picture of growth of traffic and aircraft demand, in tant market shifts will take place, with the nations of the Asia-Pacific r experiencing higher economic and air traffic growth than other regions c world. This region has had some of the most rapidly growing economies i world, and most forecasts anticipate that this pattern will continue. Fu more, integration of China, and now possibly Indochina, into the regiona global marketplace is continuing to lead to expanded international travel ciated with it. Although the region faces some uncertainty on the security in the post-Cold War era, even these potential problems seem less serious in most other parts of the world. Boeing foresees that intra-Asian trave grow at an annual rate of 8.4 percent to 2010, and transPacific travel a percent, substantially above the global average. Some of the Asian and Pacific international traffic will move on U.S.-owned airlines, but the m shift will also involve an increased role for non-U.S. airlines. McDc Douglas, for example, anticipates that the dollar value of aircraft deliver the Asia-Pacific countries will account for 39 percent of the global Whereas only Japan and Australia are among the top 10 countries in terr the dollar value of aircraft deliveries through 1992, Asia-Pacific countries account for 5 of the top 10 from 1993 through 2010 in the Boeing for (with Japan and Australia joined by China, South Korea, and Singapore). J alone is anticipated to account for $60.5 billion of the overall market for planes through 2010 (7.4 percent of global demand).

This long-term optimism about the market for new commercial ai contrasts with considerable pessimism concerning the next several years. observers believe that sales will continue to decline from their 1992 pea several more years, perhaps through 1996. Airframe and engine maker counting on a surge in new orders from U.S. airlines for delivery later i decade (aided by requirements to meet more stringent noise regulations).

Although we can be reasonably certain that growth in the demand fo travel and environmental regulation will lead to more aircraft sales ove coming decade and beyond, continuing financial pressure and structural ch in the U.S. and global airline businesses may permanently affect tradit purchasing criteria. Airline deregulation, both in the United States and i nationally, implies a continuation of strong price competition among air leading to average profit levels over the next several decades that will re lower than in the past. In this more stringent competitive environment, air will put increased pressure on the manufacturers to cut prices. This situati exacerbated by the longevity of aircraft. Even with improved performance acteristics, airlines demand that the anticipated ownership and operating co the new aircraft represent a significant savings over existing aircraft. This resents a change from the past when higher profits gave the airlines mo nancial leeway to introduce new models.

Such a shift in airline demand will lead the aircraft industry towar creased price competition; the most successful participants in all aspects c

industry will be those companies that can reduce manufacturing costs in order to maintain profitability at lower prices. Even with cost reductions, however, price competition is also likely to result in lower profit levels within the industry relative to the past, which could affect the funds available for research and development on next-generation products.

The boom-bust cycle of the airline business since deregulation in the United States is a reminder that the market outlook can change very quickly. Faster than anticipated economic growth could reopen the financial spigots and contribute to partly rebuilding the long queues for aircraft that existed several years ago. Yet even under the most optimistic assumptions, competition is likely to be fierce in most segments of the large commercial transport market.

Trends in military demand will have an indirect but significant impact on the commercial industry. Because of the steep projected declines in U.S. aircraft procurement, overall U.S. aerospace industry restructuring is likely to further accelerate and build toward a climax over the next several years. Foreign demand for U.S. military aircraft has also declined recently, and there appear to be few signs that it will pick up enough to offset much of the U.S. procurement decline. Although the political factors that influence military aircraft demand are even more difficult to foresee than commercial trends, the important point is that restructuring strategies for diversification, acquisition, and divestment are now being formulated on the basis of the current outlook. Although military and commercial businesses (including manufacturing and design) are often separated in U.S. companies—more so in airframes and structures than in engines and some component areas—many of the significant aircraft defense contractors are players in at least some aspect of the commercial business. Therefore, military restructuring has the potential to spur significant shifts in the U.S. commercial transport business. Since a number of the commercial businesses are not as visible or sensitive as prime military work and could easily be spun off, even some global consolidation through foreign investment in given industry segments should not be ruled out.

Overall, this mixed scenario for short- and long-term market trends holds the danger that some firms with good long-term prospects, mostly at the components level, will fall by the wayside. For all firms at all levels of the industry that do survive the short-term problems, success will be increasingly dependent on an ability to cut costs while maintaining or enhancing quality.

## NEW PROGRAMS

A number of new products are in the advanced stages of development and will enter service within the next few years.[4] At the airframe and engine prime levels, new programs are currently difficult to finance. The traditional methods

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[4]In aircraft, the Boeing 777; the McDonnell Douglas MD-90; the Airbus A321, A340, and A330; and the Ilyushin IL-96M; in engines the General Electric GE90, the Pratt & Whitney PW4087, and the Rolls Royce Trent.

(advances and downpayments from airlines, and commercial adaptation of gines developed for the military) have become all but unavailable over the decade. The resulting need to raise risk-sharing capital has been one of driving forces behind the growth in international alliances in this industry.

Much attention is focused on the possible development of a new genera of very large transports that could carry from 400 to more than 600 or even passengers. McDonnell Douglas's preliminary design for the MD-12 woul at the lower end of that capacity range, but the company is reluctant to lau the program without a major equity or risk-sharing partner. A planned part ship with Taiwan Aerospace fell through in 1992. Both Boeing and Airbus conducting feasibility studies and holding preliminary discussions with po tial partners concerning even larger airplanes. Japan is considered centra these discussions. Most experts believe that there is a market for one of t very large planes, and the bulk of that market is in either transpacific or mestic Japanese routes.[5] The relatively limited size of the global market terms of the total number of such planes that would be produced, leads indu experts to believe that efficiency in production implies only a single produ Furthermore, the high development costs associated with a very large airc suggest that firms will have difficulty convincing capital markets or gov ments to supply the necessary capital. Both efficiency and capital access siderations point toward an international consortium. For example, as a re of the U.S.-European Community subsidy agreement of 1992, Airbus may longer have easy access to member government funding for program lau The consortium has been actively courting the Japanese "heavies."

In other range/passenger categories, it will likely be difficult to launch new programs even if business improves. Boeing has, for example, rece decided to develop an advanced version of its 737 rather than a completely airplane in the 100 to 150-seat segment. Since this was the projected capa of the 7J7-YXX, the Boeing decision appears to have dealt a blow to Jap immediate prospect for taking a more significant partnership role in a new gram. Apart from the 80 to 100-seat and the more than 400-seat categories well as the supersonic arena, which is discussed below, there are no obv unaddressed market needs within the current market framework.

## ADVANCED TECHNOLOGY

One focus of advanced technology development for aircraft is enab technology for a second-generation supersonic transport. The major issues environmental (noise and emissions), and the keys to resolving them are in propulsion and propulsion-airframe integration areas. Even if significant p ress is made on the technical front over the next several years, an actual H

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[5] 747s are used much less on transatlantic than transpacific routes. Japan is the only country uses 747s on domestic routes.

Speed Civil Transport (HSCT) development program will be very difficult to launch. Airframers will not commit to development unless they are certain that the environmental impact will be acceptable. Also, as in the case of a very large transport, the nearer-term projected market (to about 2015) appears to allow room for only one program (although the HSCT market is expected to grow considerably in the long term). Since the bulk of the market is global and transoceanic, most observers anticipate a global program of some sort, but structuring such a program will be a complicated and difficult undertaking. Finally, extensive international government involvement, in areas such as environmental and safety certification, and infrastructure (if not program financing), will likely be necessary. Although it is possible that an HSCT will be flying at some point during the first decade of the next century, substantial technical and business-related obstacles remain.[6]

Although maintaining leadership in HSCT-related technologies is critical for the U.S. aircraft industry in the long term, *a more immediate concern is the development of technologies that can be incorporated into advanced subsonic aircraft.* The major issues are those affecting cost and quality, including process and manufacturing technologies. Airlines will demand the superior performance made possible by new technology but will not be in a position to pay premium prices. Therefore, the incorporation of new technology must not only "pay for itself" in terms of lower operating costs over the life of the aircraft, but also avoid increasing the initial unit cost. Process technology developments with the potential for raising quality while lowering the unit cost of aircraft could also affect the competitive landscape during the coming decade.

## IMPACT OF BROAD INDUSTRY FORCES

The committee has identified several broad trends for the aircraft industry during the coming decade—growing but price-sensitive markets, global restructuring, and few new programs launched by the established players. What do these trends and specific regional factors imply?

- Over the coming decade, one of the keys to survival and growth in the global aircraft market will be manufacturing performance in terms of low cost, high quality, and prompt delivery. Companies at the prime level through almost all parts of the supply chain will feel continuing pressure to achieve higher quality at lower cost.
- Japanese aircraft companies are currently investing heavily in manufacturing technology. Although a few U.S. companies are making the necessary long-term investments, many are not.[7] Japanese industry is likely to tighten its hold in current areas of excellence (structures, composite materials, engine

[6]In the event of significant continuing distress in the global aircraft industry, political pressure may mount in producing countries to launch an HSCT as an industrial policy measure.

components, flat panel displays, other electronic components, and other ponent systems such as primary actuation).

- While consolidation of the Japanese position at various supplier l will ensure that the trend toward increasing Japanese value added in com cial aircraft continues, competitive and financial pressures on U.S. primes on suppliers outside the current scope of Japanese activities will also cont It is now close to impossible to predict where this might lead and opportunities (expanded partnerships or direct investment) might be avai to U.S. and Japanese companies as a result.
- In addition to its advantages as a manufacturer, if Japanese ind can retain its traditional access to long-term capital, it will likely gain leverage in partnership negotiations for new programs. The strong econ expansion, accompanied by extremely low interest rates and financial asse flation, gave all Japanese manufacturing a temporary advantage in raising tal in the late 1980s. Although this so-called bubble is over in Japan aircraft industry remains high on the government agenda for industrial pro tion, meaning that access to policy lending from the Japan Development and other sources should continue. Identification by the government in manner should give these firms an advantage in obtaining access to comme loans as well. Overall, this Japanese industry is likely to continue its patte easier access to capital than the American industry.
- Barriers to Japanese entry into the systems integration of airfra engines, and avionics remain. The cost of maintaining and extending sys integration capabilities through new programs has increased for U.S. co nies, but the price of entry—through acquisition or accumulating expertise likely to fall, driven by excess industry capacity. An industry increasingly acterized by global partnerships and programs will allow the Japanese to tinue building a revenue and technology base to make the jump to sys integration at an opportune time after the turn of the century. *Perhaps the significant barriers to this jump are related not to inherent capabilities, b the perception of risks in the market for a "Rising Sun" jet and potentia pacts on U.S.-Japan relations.*
- It is also important to remember that the Japanese aircraft indu currently faces its own problems and challenges. The rapid appreciation o yen during 1993 and the aircraft slump have dealt a double blow to the air divisions of the heavies. Japanese government and industry are currently templating how to redeploy resources to build the industry in the future. In dition, countries such as South Korea and Taiwan have formulated nati strategies to build aircraft industries through international alliances in the manner that Japan has. In order to remain a force in the global industry, it probably not suffice for Japan to stand in place, and vision will be require move ahead.

## POSSIBLE SCENARIOS AND IMPLICATIONS FOR U.S.-JAPAN TECHNOLOGY LINKAGES

All of the possible scenarios outlined here assume that the Japanese industry will be a source both of valuable technological ties for American firms and potential or actual competitors.

### Rough Continuation of Current Trends

Even under the most optimistic circumstances, the global aircraft industry will be depressed for several more years. The U.S. industry will shrink further and consolidate. In coming years it will be increasingly necessary for U.S. aircraft manufacturers to continue to develop and invest in high-quality, low-cost manufacturing capability, as well as access Japanese manufacturing technology and stay ahead in product and design technology. Maintaining a broad-based supplier network is also critical. The danger during the current restructuring is that U.S. companies in some areas of Japanese strength will completely exit the industry. Japanese direct investment in some of these areas (materials) is already occurring and would not raise the national security concerns comparable to the acquisition of a prime contractor. Japanese companies are not awash in cash right now, but they could probably come up with sufficient funds for strategic acquisitions that make business sense (especially since the yen rate makes it attractive to move some manufacturing out of Japan anyway). U.S. acquisitions could also occur in areas where Japanese companies are beginning to establish a higher profile (engine components).

In the case of complete U.S. exit from certain key areas of the aircraft supply chain in which Japanese companies are strong, there would perhaps be no U.S. companies with an incentive to obtain Japanese technologies in those fields (except the primes in some cases). *In areas where restructuring leaves one or more U.S. companies in a position to compete with Japanese firms, the ability to make adequate long-term investments in equipment and R&D will become a critical imperative.*

One particular concern is whether U.S. aircraft primes and suppliers will be able to maintain control over their crown technological jewels in this harsh environment. It is possible that in order to survive, some companies will be tempted to make large-scale technology transfers that enable foreign industries (including, possibly, the Japanese industry) to compete more effectively with the United States. The future of the Committee on Foreign Investment in the United States (CFIUS) process (which reviews foreign acquisitions and provides a mechanism for blocking them when they endanger national security) is unclear, and the recent trend has been toward a relaxation of export controls. Therefore, barriers to the outflow of significant U.S. aircraft technologies may be lowered in coming years.

## Asian Airbus

Some analysts discuss the possibility of an Asian Airbus, particularly of the existing airframe primes exits the business. Some believe that th sibility has been enhanced in recent years by Japan's industrial cooperati aid policies in Asia.

Although possible, a Japanese-led Asian aircraft consortium would b difficult to put together. The Japanese have shown reluctance to make the risky investment needed to enter the market as a prime integrator, an strategy would appear to be the most expensive and risky of them all. would be the logical country to lead a viable Asian aircraft consortium, b hard to conceive of China, Korea, and Taiwan (countries with large a markets) rushing to sign up. This would leave a Japan-led consortium v able to a number of counterstrategies. In fact, Japanese press reports speculated about an Asian aircraft consortium that would exclude Japan.[8]

## Asia/Japan Cooperation with Airbus

Still another possibility would be an alliance involving Airbus and aircraft industries. Airbus has been courting Japan in recent months, and industrializing countries in Asia are anxious to promote domestic indu Although it seems unlikely that all of these countries would team with (and jeopardize linkages with U.S. companies and traditional relationship the United States), a group of them might be stimulated to do so. The is reallocating Airbus work share to make room for the Asian partners cou prove to be a stumbling block to such an alliance.

## Japan Squeezed

Especially if Japan makes aggressive moves to increase its global pr (by making a major acquisition at the integrator level, launching an inde ent program, aggressively playing both sides against the middle in its in tional alliances, or other circumstances), it is possible that the Japanese h in particular could be squeezed by companies from other nations follo similar strategy. The Japanese have moved quite far down the experience in making aircraft structures, but the main requirements necessary to d sort of work are general manufacturing excellence and lots of patient cap would not be impossible for Korea or Taiwan (or others who have m known they are available) to emulate Japan, particularly if one of the airframe manufacturers has a strong incentive to put one of these count business. However, this scenario is less likely to affect some materia

[8]See "YSX Keikaku in fuan no tane" (Seeds of Doubt for YSX Plan), *Nihon Keizai S* October 14, 1993, p. 11.

components manufacturers (such as Toray and Hosiden) because of their existing strong global market positions.

### Russian Wildcard

The Russian aircraft design bureaus possess considerable design capabilities. Although it appears that the Russians have been quicker to team with U.S. companies than with firms from Japan, over the long term the combination of Russian integration and design skills with Japanese capital and manufacturing know-how would seem to represent a potentially powerful combination. While the two industries have agreed to launch some small-scale collaborative activities, considerable obstacles remain to a smooth Russian-Japanese working alliance in aircraft design and manufacturing.

### Resurgent U.S. Industry

Even in the current tough business climate, some U.S. companies are making the long-term investments in technology and R&D necessary to retain leadership in this industry. The concern is that if current trends continue, many U.S. companies will not make these investments and large segments of the U.S. industry will face severe challenges to their survival. However, the opportunity now exists to take steps—at the corporate and national levels—that can change these trends and enable the United States to retain its technological strength, maintain a full-scale manufacturing base, and compete strongly in world markets on the basis of superior technology, design, and manufacturing performance.

By introducing advanced technologies into new aircraft while lowering manufacturing costs, U.S. companies can take advantage of continuing upheavals in the global industry to reenergize their leadership. The keys to creating conditions in which a resurgence of U.S. leadership in aircraft manufacturing can take place are outlined in the following chapter.

# 5

# Conclusions And Policy Recommendations

## THE GLOBAL CONTEXT AND U.S. NATIONAL INTERESTS

Aircraft manufacturing is critical to America's long-term economic gr and national security. In terms of the economy, it is a major factor in dom employment and international trade; in terms of security, U.S. airpower played a major role in strategic nuclear deterrence, and the Gulf War cl demonstrated the importance of modern, technically advanced aircra America's military superiority. Additionally, this industry is global—not in its markets and its basic mission, but also in its industrial structure, tech talent, and financing. Finally, aircraft development requires enormous ca investments (tens of billions of dollars) whereas payback is achieved only the long term and individual programs face a high risk of never breaking e It is this combination of factors that makes the aircraft industry both un and of significant national importance. Thus, it has historically been sin out for government support—particularly through advanced research fun by the National Aeronautics and Space Administration (NASA) and thr R&D and production funding by the U.S. Department of Defense (DOD).

Today, the U.S. aircraft industry remains a world leader, but significant adjustments will be needed for it to remain so in the future. Over the next decade, U.S. industry will continue to come under increasing international competitive pressure. The aircraft industries of Europe, Japan, Russia, Taiwan, China, and other nations are aggressively seeking opportunities to tap into the expected long-term growth in commercial aircraft markets. Forecasts for growth in the Asian market are particularly impressive. Heightened international competition will take place in an environment of unprecedented U.S. industry restructuring as a result of dramatic reductions in the defense budget. Therefore, U.S. industry will be severely challenged over the next decade just to hold its current position in global aircraft manufacturing. Achieving growth in global market share will be an even more difficult task.

This study of U.S.-Japan alliances illustrates the key features of this evolving global competitive environment and highlights the broad challenges faced by the U.S. aircraft industry. In order to reenergize U.S. leadership in the face of these challenges, a new approach must be developed by industry and government.

*Conclusion*

- *Leadership in aircraft design and manufacturing—including a full spectrum supply chain—remains a vital U.S. national interest.* In order for the United States to maintain its leadership position in this critically important industry, it is essential that aircraft be singled out for specific, strong, government-industry partnering in the development and implementation of a long-term strategy.

## THE JAPANESE AIRCRAFT INDUSTRY

Japan is currently a significant player in global aircraft manufacturing. Japanese companies are formidable competitors in a number of aircraft subsystem and component areas. Although Japanese industry is not competing today at the prime integrator level, Japan already possesses or could acquire the capabilities needed to do so. The committee has seen that Japan is making the long-term investments necessary to be a world leader in air transport design, development, and manufacturing. Japan's primary strength lies in the manufacturing capabilities of its companies, and Japanese firms are focusing on low cost and high quality as differentiating factors.

Japan has established an aircraft industry as a matter of national policy with managed internal competition but with a resilience to changing economic conditions. Technological, financial, and human resources are leveraged across civil-military, supplier-prime, and horizontal interfaces to maximize industry's long-term competitive position. Strong industry-government partnership in formulating and implementing strategies in the aircraft industry has long been

a key feature of the Japanese environment. These characteristics of the Ja aircraft industry will serve it well as it seeks to expand its global prese the post-Cold War competitive environment.

Japan is committed to deepening its capabilities across a range of a related technologies and to increasing its presence in the commercial market.[1] Japan's current strategy is to develop international linkages to a these goals. Japan has more options today in terms of international li than it has ever had (Russia, Europe, etc.), and U.S. government and in should not assume that they have a lock on the action.

*Conclusion*

- *Japanese industry's role in global aircraft manufacturing, desig technology development will continue to grow.* Japanese industry reta option to enter the market as a prime integrator and/or to further expa scope of its international alliances. Although currently facing difficulti Japanese industry has inherent strengths that will see it through the downturn and allow it to emerge as a more formidable competitor in b tablished and emerging areas.

## U.S.-JAPAN TECHNOLOGY LINKAGES

The 40-year modern history of cooperation between the United Stat Japan in the aircraft, and associated subsystem, industries has been positive for both sides. Japan has used linkages to build its technologic manufacturing capabilities in military and commercial aircraft prod American industry has earned significant revenues from Japan through a sales and licensing, as well as the benefits of effective business partnershi

Characteristic linkage mechanisms have evolved from licensed ma turing of U.S. designs to the present stage in which a number of allian volve the design of significant components and subsystems by Ja aerospace companies. We now appear to be entering a new stage, partly s by several Japanese initiatives, of more extensive cooperation in majo space R&D programs (such as the FS-X and HYPR).

U.S.-Japan linkages can continue on a constructive basis, provided t balance and fairness in the flow of technologies. Here, the challenge United States is to continue to build effective U.S.-Japan relationships,

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[1] Recent news reports on renewed efforts to line up partners for a YS-X feasibility st Mitsubishi Heavy Industries' (MHI) participation in Bombardier's Global Express business jet (MHI will manufacture the wings and center fuselage) underscore the intention of Japanese indu government to push forward in aircraft despite tough economic times. See Christopher J. "Bombardier Board Approves Plans for Corporate Jet," *Wall Street Journal*, December 20, A5; and "YSX, Nichi-Bei-O-Chu de Kaihatsu" (YSX to Be Developed by Japanese-U.S.-E Chinese Partnership), *Nihon Keizai Shimbun*, December 28, 1993, p. 1.

developing a sharper focus on defining the technologies that we want to flow to U.S. industry, as well as those that we should maintain domestically.

In maintaining its leadership and meeting the global competition, the overall U.S. approach must not be "protectionist" or "defensive" but proactive—to maintain U.S. leadership and enhance U.S. capabilities. Markets and technology development in this industry are global—Japan and the rest of Asia are of increasing importance in both areas. U.S.-Japan and other international technology linkages are facts of life and likely to increase globally in this industry. Efforts must be made to structure alliances with Japan so that they enhance U.S. access to Japanese technology, markets, and capital.

*Conclusion*

- *The challenge for U.S. industry and government is to stay ahead,* using technology linkages with Japan as part of a strategy to build capabilities needed for a strong domestic manufacturing and technology base and an industry consistently capable of effective global competition.

## DEVELOPING A U.S. STRATEGY

The majority of the actions needed to maintain America's leadership position in the aircraft industry and to ensure mutually beneficial relationships between American and Japanese firms must be the responsibility of the U.S. aircraft industry itself—both prime integrators and the supplier base. However, it is also clearly necessary for the U.S. government to create a favorable overall environment for these actions, as well as play a specific role in creating incentives or actually making selected, limited investments. Providing the desired overall environment and assistance requires both a long-range strategy and an institutional structure to implement it. Currently, neither the strategy nor the needed institutional mechanisms exist.

The committee therefore recommends a five-part strategy to address U.S.-Japan relationships and the larger competitive challenges facing the U.S. aircraft industry. The objectives are to revitalize U.S. aviation leadership (both in technology and in market share) and to maintain a significant, full-spectrum domestic engineering and manufacturing base. The five elements of a comprehensive U.S. strategy include:

1. maintaining U.S. technological leadership,
2. revitalizing U.S. manufacturing capabilities,
3. encouraging mutually beneficial interaction with Japan,
4. ensuring a level playing field for international competition, and
5. developing a shared U.S. vision.

## Maintaining U.S. Technological Leadership

U.S. leadership in aviation is largely the result of a continuous, lo
stream of investment that has supported the development of a wide r
advanced technologies. This investment has come from the private
public sectors. The current massive restructuring on both the military
commercial sides of the aircraft business makes it critical that U.S. tec
cal leadership be maintained. Industry, NASA, and DOD all have a vita
play; and other agencies (Department of Transportation/Federal Aviat
ministration, Department of Energy, Office of Science and Technology
National Economic Council) also are significantly involved.

*Clearly, aviation is an area in which the best policy for future U*
*nomic growth is to stay ahead.* Other nations, including Japan, Europe,
and China, are focused on this industrial sector, and U.S. industry's
logical lead has narrowed considerably in recent years. For some time t
ian aviation arena has been characterized by incremental techn
advance, rather than by dramatic breakthroughs comparable to the high
engine. Partly for this reason, aircraft manufacturers currently face
price pressure. The Japanese have recognized this trend and are now f
on low-cost, high-quality manufacturing as a differentiating feature. I
industry to survive and grow in this environment, the United States sho
steps to overhaul and refocus aircraft-related R&D activities.

What the United States must do is strive for quantum improvemen
application of process as well as product technologies. This will involve
and meeting concrete targets—such as lowering the unit and life-cycle
aircraft and of air travel for advanced subsonic aircraft and the next-ge
high-speed transports by one-third or more. The entire system will ne
addressed—from the cost of aircraft and engines, to fuel efficiency,
nance, reliability, and airport air and ground operations.

This will require a significant restructuring of the large R&D inve
government makes—mainly through NASA and DOD—in order to
greater efficiency and commercial impact. The committee supports N
recent initiatives to increase research on subsonic aircraft and propuls
tems. NASA should continue on this course by aggressively increasing
phasis on developing cost-effective, product-applicable technologies, in
the flow-through of R&D funding to industry, and supporting greater c
tive efforts among U.S. companies. Particularly in the subsonic area, an
tant focus should be on lowering the cost to industry of incorporati
technology in aircraft and related systems. Although greater attention
sources should be devoted to advanced subsonic aircraft, NASA's par
with industry in high-speed civil transport research should also contin
high priority.

The Department of Defense aircraft R&D budget for enabling tech
must be maintained at current levels despite overall cuts in the defens

(see Figures 2-2 and 2-3). DOD should also reorder its procurement and R&D funding priorities to promote integration of military and civilian systems. As in the case of NASA funding, more emphasis should be placed on cost-effective technologies. The issue of civil-military integration is treated in more detail below in the discussion of revitalizing U.S. manufacturing capabilities, but this goal should be a focus of Department of Defense R&D spending as well. The committee is encouraged by recent initiatives[2] and the stated positions of DOD officials, but the barriers to changing old ways of thinking and doing business should not be underestimated. Some aspects of the Japanese experience are instructive. For example, working with fly-by-wire technology on the T-2 trainer helped maintain Japanese industry's strong position in primary actuation, and Japanese strength in microwave integrated circuits for civilian applications contributed to the development of the FS-X phased array radar.

In addition, U.S. industry must continue to invest its own resources in new technology development. For many aircraft and aerospace companies, this is a difficult prospect in the current environment. Even companies that now have a healthy cash flow may be reluctant to make long-term investments because of uncertainties related to ongoing industry restructuring. In addition, the recently renewed R&D tax credit does not serve as an incentive for companies shifting from military to commercial applications unless the overall amount of R&D spending increases. By working closely with industry in its technology development programs and modifying the tax credit, government could help industry maintain the necessary level of R&D investment.

Finally, cutting-edge academic research in fields such as computational fluid dynamics also makes a substantial contribution to U.S. capabilities. A number of government agencies fund relevant academic research (NASA; DOD through the Advanced Research Projects Agency, Air Force Office of Scientific Research, and Office of Naval Research, and the National Science Foundation). Currently, there is no coordination of this investment across agencies. In recent years the federal government had begun to coordinate some of its technology activities through the Federal Coordinating Council on Science, Engineering and Technology, an initiative that the current Administration has consolidated with other interagency policy councils, establishing the National Science and Technology Council. The High Performance Computing and Communication Initiative is another good example. Agencies funding aeronautical research at universities should establish a similar committee that incorporates industry input in order to achieve a better focus on work relevant to industry.

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[2]An Advanced Research Projects Agency initiative on "low-cost aircraft" and an Air Force initiative on "lean aircraft manufacturing" are recent examples.

*Recommendations*

- The 35 percent increase in NASA aeronautics R&D funding for f 1994 is a step in the right direction, and efforts should be made to continue percentage increase for the next three years, primarily through realloc within NASA.[3] NASA should further expand its enabling technology I programs in subsonic aeronautics and propulsion systems, with the pri objective of reducing the initial investment and operating cost of future air and subsystems.
- NASA's traditional role in basic research should be expanded t clude nearer-term, product-applicable technologies. This will involve su for more technology demonstrations aimed at lowering the cost to produce erate, and support aircraft incorporating new technology.
- NASA should significantly increase the share of aeronautics fun contracted to industry (currently 17 percent) with the objective of reachin percent over the next five years, in particular, targeting technologies releva suppliers.
- DOD should maintain the current level of R&D support allocate the development of advanced "enabling" technologies for the aircraft ind at both the prime and, particularly, the subcontractor levels.
- The committee supports other groups that have called for the R&I credit, which was recently extended for two years, to be made permanen also believes that a mechanism should be developed to avoid penalizing panies that reorient their R&D from defense-unique to dual-use or comme areas. The focus should be on creating incentives for greater commercial dual-use R&D investments, even if the level of defense R&D is reduced.
- An interagency body should be created to coordinate—with ind cooperation—federal government investment in university and national lal tory research in aerodynamics and other related fields (e.g., computer sci and materials science).

## Revitalizing U.S. Manufacturing Capabilities

In view of the global competitive environment of continuing cost pres on aircraft manufacturers, U.S. primes and suppliers will have to contin improve manufacturing performance in terms of cost, quality, and delive remain competitive. This is especially critical in light of the large investn in state-of-the-art equipment being made by the Japanese aircraft indu While some U.S. companies are making the necessary investments, man

[3]By using the FY 1994 authorization of $1.69 billion as a baseline, this would im aeronautics budget of about $4 billion in FY 1997.

[4]See National Science Board, *The Competitive Strength of U.S. Industrial Scienc Technology: Strategic Issues* (Washington, D.C.: U.S. Government Printing Office, 1992), p. 4

finding it difficult because of the current commercial aircraft slump and defense cutbacks. Although an aircraft industry structure with fewer U.S. players at various levels is perhaps inevitable, it is important that the remaining companies—particularly the supplier networks—have the wherewithal to match or exceed the manufacturing performance of Japanese and other international competitors.

There are four major aspects to ensuring that the U.S. aircraft industry develops world-class manufacturing capability. First, companies themselves must make the necessary investments in new equipment. Other groups have called for the reintroduction of an investment tax credit.[5] Although the committee is well aware of the severe budget environment, its view is that a tax incentive structured to encourage companies in this capital-intensive industry to stay on the cutting edge of manufacturing technology would be in the national interest.

The second requirement for revitalizing U.S. manufacturing capabilities in aircraft is greater civil-military integration to increase the economic impact of DOD aircraft spending. This should be a priority in DOD aircraft R&D, production, and support investments. DOD spending has a pervasive influence on the business activities of aircraft companies—including investment and manufacturing. Over time, there has been a dramatic widening of the gap between military and civilian aircraft R&D, engineering, and production within firms in the United States. This is apparent in the major technical issues that have become the focus of military aircraft development over the past several decades, such as stealth and high maneuverability, which have little commercial relevance. Although DOD will continue to have some unique requirements, efforts to increase the dual-use applicability of defense systems and components wherever possible would lower procurement costs and support the commercial competitiveness of defense contractors.

The benefits to industry of a more dual-use oriented defense industrial base might be greatest in terms of manufacturing. For example, both Boeing and McDonnell Douglas have found it prudent to separate military and commercial transport work because of the significantly higher administrative and other costs associated with defense contract work. The potential benefits of removing these barriers are likely to be even greater in the supplier base. Thus, DOD must provide incentives for companies to integrate their military and commercial production, and reduce the huge barriers to civil-military integration—including cost-accounting standards, military specifications, procurement practices, and rebalancing DOD's stress on performance versus cost. The Japanese aircraft industry is achieving plant integration in its advanced aircraft manufacturing operations—in areas such as composites and metal parts—for the FS-X fighter and the 777 transport. The committee commends recent

[5]Council on Competitiveness, *Technology Policy Implementation Assessment 1993*, (Washington, D.C.: Council on Competitiveness, 1993), p. 6.

statements by DOD officials indicating that tackling this problem is a top p ity, and urges timely and vigorous follow-through.

A third requirement for ensuring a strong U.S. aircraft manufacturing is building more effective vertical relationships between firms at all leve the supply chain. The importance of these relationships for advancing sta the-art manufacturing is obvious in some areas—such as the relationshi tween structures manufacturers and machine tool builders. Effective sup relations can significantly improve design and manufacturing performan terms of cost, quality, and cycle time throughout the aircraft manufact infrastructure. This is one of the key strengths of the Japanese aircraft indu

Most of the responsibility for building vertical links that improve the formance of the U.S. aircraft manufacturing system lies with the comp themselves. There is evidence that a number of U.S. primes and supplier making positive changes—particularly on the commercial side of the ai business, where some primes are increasingly recognizing the long-term fits of closer, more stable links with suppliers and are instituting programs help increase supplier capabilities. However, policy changes should creat centives that support and expedite this process, particularly on the defense Although the Department of Defense has made efforts to encourage effective relationships, further changes in R&D and procurement funding tract mechanisms could encourage closer cooperation between U.S. firms their suppliers, leading to lower costs and greater technology sharing i long run. The occasional practice of "breaking out," or putting the supp parts for ongoing programs up for international competitive bids, has an cially adverse impact on the supplier base. R&D and procurement funding contract mechanisms should encourage, rather than discourage, cooper among U.S. companies.

The fourth aspect of revitalizing U.S. aircraft manufacturing is R&I the additional funding for aeronautics and aircraft-related R&D recomme above by the committee, a significant portion should be devoted to pr technology development. DOD's Mantech program is an existing mecha that a number of U.S. companies have found delivers significant benefits.

*Recommendations*

- *In order to maintain global leadership, U.S. aircraft manufactur both primes and suppliers—must invest in high-quality advanced manufa ing processes* that will position them to compete as low-cost, high-quality cycle time producers in the years ahead. Introduction of a tax incentive for ductivity-enhancing investments should be studied. The tax credit shou targeted to investments by lower-tier suppliers in technologies considered cal, or to investments in advanced manufacturing equipment and training.
- The Department of Defense should reform the procurement syste

extensive use of commercial item descriptions, greater emphasis on low cost and high quality in addition to performance, provision of data bases and training to enhance the use of commercial specifications,[6] and increased use of commercially available components and processes. Perhaps most important, DOD should reduce, to the extent possible, barriers to utilizing common manufacturing facilities for military and civilian aircraft production through revision of its accounting and oversight requirements, military specifications and standards, and procurement practices.[7]

- The committee concurs with recent Defense Science Board recommendations on low volume production and further recommends that DOD explore steps toward revitalizing U.S. aircraft manufacturing capability, such as carrying prototype aircraft systems and subsystems forward in limited quantity fabrication in order to demonstrate low-cost "manufacturability" in addition to specified performance.[8]
- The Department of Defense should modify its procurement and R&D funding mechanisms to eliminate current disincentives for long-term prime-supplier relationships that enhance quality and lower costs.
- As part of a stronger emphasis on technologies that are applicable in the near term and contribute to lowering aircraft and air travel costs, NASA and DOD aircraft-related R&D programs should place a high priority on manufacturing and design processes.

### Encourage Mutually Beneficial Interaction with Japan

The committee recognizes that U.S.-Japan alliances that transfer or develop technology are a fact of life in this industry. Cooperation with Japan has delivered significant benefits to the U.S. aircraft industry over the years, which have been outlined above in the discussion of distinctive features of U.S.-Japan linkages. Yet technology transfer to Japan also carries risks for individual companies and U.S. industry as a whole. In addition, the environment surrounding U.S.-Japan linkages has evolved significantly. Japan's growing technological and manufacturing capabilities, as well as the passing of the Cold War context in which alliances were structured in the past, necessitate a new approach by the United States to ensure that the benefits of cooperation are maximized and the risks are managed.

U.S. government and industry must create new mechanisms and devote additional resources to encouraging mutually beneficial U.S.-Japan relationships in several key areas: (1) technical information management and technol-

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[6]See Center for Strategic and International Studies, *Integrating Commercial and Military Technologies for National Strength* (Washington, D.C.: CSIS, 1991) for a detailed analysis of more specific options on specifications and fostering military-civilian synergies.

[7]For example, DOD's Manufacturing Quality Requirements have been revised recently to permit integration of civilian and military production in the electronics area.

ogy benchmarking; (2) identification, valuation, and control of c technologies; and (3) education and training. Although Japan-related act may require special attention and greater resources, it should not be th focus of this new approach—the U.S. aircraft industry's technology lin are global, and greater efforts to maximize the benefits of international eration should reflect this.

*Information Management and Technology Benchmarking*

Competitiveness in high-technology industries such as aircraft depend great extent on how quickly products can be brought to market. Reducin sign and production time requires an efficient use of resources, both huma technical. The U.S. technology infrastructure is loosely linked, and init has a strong "bottoms-up" orientation. This structure promotes innovatio often inhibits the diffusion of technology.

The U.S. government, by virtue of its broad information collection bilities, is in a unique position to gather, package, and disseminate technical and business information from global sources to U.S. industry though this is an appropriate general role for government, collection, coo tion, and dissemination efforts require a stronger industry focus than they received up to now. Aeronautics could be a test case for a new approach U.S. government already has several programs that are relevant to this For example, the Japan Technology Evaluation Center (JTEC) overseen National Science Foundation (NSF) has conducted numerous studies in years that benchmark Japanese technologies. Several of these studies have funded by NASA or DOD and have examined aerospace-related techno such as advanced composites and supersonic/hypersonic propulsion.

In addition to existing programs with relevance to Japan, other U.S ernment agencies collect, translate, and disseminate a variety of technica business-related information of potential use to the U.S. aircraft industry.[9] is required is a coordination mechanism with strong industry input that f these efforts. The most logical place for this coordination function Technology Administration of the Department of Commerce. This effort s ensure that U.S. government information activities are tied to U.S. in needs, and should permit a broader spectrum of U.S. industry to access knowledge on Japanese aircraft technologies and industry activities.

The committee believes that it is also necessary, as part of this new to support U.S. industry access to information through an industry outp Japan. Although most of the large U.S. aerospace companies maintain a ence in Japan, and the American Aerospace Industry in Japan (AAIJ)

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[9] Another relevant activity is the information exchange being launched between NASA and National Space Development Agency. See Laurie Harrison, Glenn P. Hoetker, and Thomas "Access to Japanese Aerospace-Related Scientific and Technical Information: The NASA Ae Database," *Japanese Technical Literature Bulletin*, June 1993, p. 1.

sents their common interests, many smaller U.S. companies do not have the resources to maintain a Tokyo office. Even the large companies focus their Japan efforts primarily on marketing rather than on technology access and related issues. A U.S. government-funded industry outpost in Japan—directed by a technically trained American fluent in Japanese—could serve as a source of "on the ground" information and as a liaison to Japanese government and industry. For example, some Japanese government advisory committees (*shingikai*) have invited foreign participation in recent years. The U.S. industry liaison would be available to participate in—or at least track—these advisory activities.

Another area in which new approaches to dissemination are needed is information on the flowback of Japanese technical improvements and indigenous Japanese technologies through specific U.S.-Japan military aircraft programs—most notably the FS-X. The Department of Defense and the Department of Commerce are already making a contribution in this area, but additional efforts are necessary. For example, the wide range of opinions expressed about the value of FS-X technologies such as the composite wing and advanced avionics to U.S. industry illustrates the need for a more systematic effort. Sufficient resources should be made available for the responsible agencies to catalogue and distribute flowback data on an industry-wide basis.

### *Identification, Valuation, and Protection of Critical Technologies*

U.S. government involvement in technology linkages between U.S. aircraft manufacturers and international partners has occurred mainly in the context of the export control system. U.S. government involvement has been extensive where government-to-government agreements on bilateral or multilateral military programs are required (F-15 licensed production and FS-X codevelopment with Japan; F-16 coproduction with several European nations). Even for purely commercial links, export licenses are sometimes required because of the dual-use character of the technologies involved (Boeing's joint work with Japan on the 7J7), and in rare cases, alliances have been the subject of discussions at the highest levels of government (the formation of CFM International).

The future U.S. government role in international transfers of aircraft technology is unclear. There has been a relaxation of export controls resulting from the end of the Cold War. The committee believes that while this is mainly a positive trend, it is important that the United States, for national security reasons, retain export controls on a limited number of critical aerospace technologies.[10]

The committee further believes that outside the few identifiable critical areas covered by export controls, actual negotiations for technology transfer and

[10]A longer-term reorganization of the system to increase clarity and user friendliness may be

other international collaboration are the responsibility of U.S. compani teams of U.S. companies) negotiating with prospective Japanese partners Japanese government. Companies themselves are normally the best jud what relationships will serve their own long-term growth and interests, b tional and corporate interests sometimes diverge. In addition, the lon impacts of technology transfers are often difficult to predict. In the U.S. context, the semiconductor industry provides a useful example. U.S. com licensed the key basic technologies for semiconductor manufacturing to nese industry in the 1960s, under conditions in which access to the Ja market was severely limited.[11] It was not until years later that the Ja semiconductor industry developed into a formidable competitor.

The U.S. aircraft industry has often transferred technology abroad in to enhance market access, in many cases without a commensurate return nology flow. This historical pattern is understandable given the large technological capabilities that often existed between U.S. industry and foreign partners. However, in the current environment of intense global petition, U.S. industry cannot afford to ignore the increasing sophisticat its overseas partners and must aggressively pursue a balanced flow of te ogy wherever possible. Especially in the current business context in whi ternational alliances are a fact of life, U.S. industry must make the best possible. Yet what distinguishes "good deals" from "bad deals"? Althoug experts might differ over particular cases, the accumulated knowledge a pertise of U.S. industry regarding technology transfer in international all constitute a valuable resource. Past experience and current imperatives s the need for an independent body to develop guidelines for technology tr consistent with national interests.

More systematic consideration should be given to identifying and p ing critical aeronautical technologies at both the company and the in levels. The committee believes that a most promising approach is to estab new mechanism aimed at drawing on and disseminating the accum knowledge of industry and other experts. This effort led by the private could be a valuable resource for companies as they negotiate international nology alliances, the ultimate goal being to expand the data base requi properly value corporate technological assets and to structure internation operation that brings clear economic and technological benefits to the States. This could be accomplished by a working subgroup of a new Na Aviation Advisory Committee, which is described in greater detail below activity ideally should incorporate the following tasks:

1. Publish and periodically update a description of the critical techno for the aircraft industry, to be used as an informal input for company de

making and for government R&D funding and international benchmarking activities.

2. Develop guidelines covering the international transfer of commercial aerospace technology—including the development of data and methods for valuing technology—that would help corporate managements make and objectively evaluate technology transfer decisions.

3. Carry out periodic assessments of international technology transfers and measure progress toward increasing the flow of aerospace technology into the United States, including acquiring the data needed to undertake these assessments.

*Education and Training*

American universities and research institutions play mainly a background role in U.S.-Japan linkages in the commercial aircraft industry. Nevertheless, this role can have a crucial impact on moving toward more productive and balanced technology linkages. This occurs primarily through the training of American engineers, scientists, and managers in Japanese language and area studies. Educational programs at American universities constitute an important vehicle for building awareness of Japan as a global competitor, and for providing students with the information and skills needed to interact with the Japanese in a more productive way (presumably enabling an enhanced flow of technology from Japan to the United States).

A number of university programs have been established in recent years to train young scientists, engineers, and other professionals in Japanese language and technology management. Three years ago, DOD (through the Air Force Office of Scientific Research) launched a mechanism to fund such programs, in order to increase the effectiveness of those already existing and to spur the formation of new centers.[12] As a result, a larger pipeline exists for training technologists and managers to operate effectively in a Japanese environment. Several U.S. aircraft companies are hiring graduates of these programs. Closer interaction between industry and university programs of this type would lead to mutually beneficial impacts, including employment of qualified graduates, internships for students, and training programs tailored to industry needs.

Education and training also have a bearing on technology outflow. In addition to technology transferred to overseas partners through licensing agreements, some technology flows out inadvertently as a result of inexperience or lack of training. Many employees do not realize that valuable technology can be transferred in a casual conversation or in activities such as a presentation to a professional society. Nor do they realize that their company's commercial technology may be specifically targeted by their foreign competitor or would-be

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[12]National Research Council Committee to Assess U.S.-Japan Industry and Technology

competitor. "Ego" also comes into play as engineers try to impress their contacts with their knowledge and accomplishments, a characteristic e aged by potential foreign competitors eager to acquire technology.

It is in the general interest of U.S. industry to lessen this inadverten nology outflow. Training programs and processes patterned after those protect DOD classified technology and information should be instituted industry level for companies establishing international alliances. The ob of the training and processes would be to make all employees knowledge what type of technology should be protected and what they must do to pro In addition, employees who are going to interface regularly with foreig petitors should, whenever possible, learn the language of their counte This could be augmented by Japan-specific training for negotiations an nical interaction—perhaps instituted as an industry outreach activity by more of the university-based Japan technology management centers.

*Recommendations*

- The Department of Commerce should consider using the industry as a test case for a new approach to coordinating infor collection and dissemination activities in various agencies, the goal be increase the utility of government information to industry. This effort incorporate regular technology benchmarking and include the establishm a small aircraft industry outpost in Japan.
- The Departments of Defense and Commerce should devote add resources to a systematic program of cataloguing, evaluating, and disse ing to industry information about technology flowback and indigenous Ja technologies in connection with the FS-X and other collaborative milita craft programs. An important goal of this effort should be to establish for making judgments about the potential value of this technology to DO U.S. industry, and to improve U.S. access to Japanese manufacturing te ogy when there are both a demonstrated U.S. need and potential users.
- One of the central tasks of a new National Aviation Advisory Co tee should be to support U.S. industry decision making in the areas of technologies and international technology transfer. A working subgroup new committee should identify critical technologies, develop guidelines transfer of aerospace technology, and conduct periodic assessments of i tional technology flows.
- University-based programs that provide Japanese language and agement training to young technologists and other professionals strengthen interactions with the U.S. aircraft industry to help meet ind need for managers and technologists who can interact effectively with Ja counterparts.
- The U.S. aircraft industry should collaborate to develop a t program for employees involved in technology exchange to enhance pro

of critical technologies and effective technology transfer (both inflow and outflow) where appropriate.

## Ensuring a Level Playing Field for International Competition

Japan has no formal barriers to aircraft imports, and to this point its industry subsidies have not caused massive distortions of international markets. However, in light of heightened international competition in all segments of the aircraft industry and the inclination of governments to be heavily involved in the development of national industries, U.S. trade policy must be a key element in any U.S. strategy for the aircraft industry.

Continued U.S. leadership in aircraft requires that trade policy support fair global competition by limiting massive government subsidies to competitors. Although the issue was set aside in the agreement reached in the Uruguay Round negotiations of the General Agreement on Tariffs and Trade (GATT), it may be possible to gain agreement on multilateral trade rules that protect the interests of the U.S. aircraft industry. Goals for such an agreement include the multilateralization of last year's bilateral Agreement on Large Aircraft (which bans production supports and limits new program development financing) between the United States and the European Community, as well as a strong Subsidies Code agreement that applies to aircraft and provides for disciplines on export subsidies and a dispute settlement mechanism. Trade negotiations are particularly important in light of the emergence of new aircraft manufacturers not currently bound by all of the relevant GATT disciplines (Russia, China, and Taiwan). In formulating strategies for multilateral negotiations, the U.S. Trade Representative should work closely with industry.

Another aspect of supporting U.S. industry's position in international markets is the financing support of the Export-Import Bank. Export-Import Bank financing was very important to U.S. aircraft exporters during the 1970s, but its role declined during the 1980s. Over the past two or three years, Export-Import Bank guarantees have again become an important factor in the export of U.S. aircraft due to the deterioration in the financial strength of airlines worldwide. The U.S. government should ensure that Export-Import Bank guarantee and lending authority for aircraft exports is sufficient to meet sales opportunities.

### *Recommendations*

- In order to support the position of the U.S. aircraft industry in international trade and ensure a level playing field, the U.S. government should strive through trade negotiations to achieve multilateral rules that will govern and reduce subsidies.

- The U.S. government should also maintain recently increased Import Bank guarantee and loan authority to the extent needed to tak tage of export opportunities.

## Developing a Shared U.S. Vision

The committee believes that the four elements of a U.S. aircraft strategy and the associated recommendations for action outlined above essary and stand on their own terms. However, the critical importanc industry and the rapidly changing context demand ongoing high-level to these issues in order to ensure that a strategy is implemented. C American leadership in this industry also requires that the United Stat more effective working relationships within industry and between indu government.

This study of U.S.-Japan aircraft linkages and the Japanese aircra try highlights the need for a new approach. The committee has se Japan's aircraft industry—both prime contractors and suppliers—wo government to maintain and constantly upgrade skills and technolog pabilities. Despite the industry's small size and the fact that Japanese nies are not among the major global players in prime integration, aircraft manufacturers are well established as key suppliers in the glo kets for commercial transports and engines, mainly as partners in prog by U.S. primes. Over time, the level and sophistication of Japanese p tion in these programs have steadily increased.

Strong, stable relationships between Japanese primes and supplie that technologies are diffused and benefit the entire aircraft manu network. The Japanese aircraft industry currently faces a number of ch as a result of civilian and military market contractions and exchange ra but the committee believes that the industry's demonstrated ability to as a system will allow it to weather these shocks and emerge as a global partner and competitor in the future.

International alliances, particularly those with U.S. compani played and continue to play an important role in the development of t nese industry. Collaboration on both the military and the commercial been supported by the Japanese government and has been structured to steady flow of aircraft-related technologies from abroad, as well as to opportunities for Japanese companies to develop and enhance indigen nological strengths through their program participation.

Although the U.S. aircraft industry has great strengths, and it wou possible or desirable to duplicate the Japanese system here, contras situation with Japan's highlights the challenges that we face and the need to cooperate and utilize resources more effectively. The Unite spends a significant amount on aircraft-related R&D, yet its technolog has narrowed in recent years. Although it would be impossi

counterproductive to ensure that every aircraft prime contractor and supplier remains viable during the current period of restructuring, we face a greater risk of losing some critical capabilities altogether because our prime-supplier relations are more arm's length and less extensive than Japan's.[13] Although larger U.S. aircraft companies have gained demonstrable business and even technological benefits from their relationships with Japan, the impacts on the supplier base have not been as beneficial, and the bargaining power of even the strongest U.S. companies has been affected by the necessity of competing with each other in negotiations with a coordinated Japanese industry.

As has been pointed out elsewhere in this report, the major challenges faced by the U.S. aircraft industry are broad and generic—current weakness in the global market for commercial aircraft, declining defense procurement, and tough competition from a range of established and new international players. Competition from Airbus is obviously immediate and significant in airframe integration, and other national industries such as Russia's may pose a challenge in the future. Although this assessment demonstrates the need for a shared vision for the U.S. aircraft industry, developing this vision will require a comprehensive approach.

In order for the U.S. aircraft industry to maintain a full spectrum of design, technical, and manufacturing activities in the United States and link itself more effectively with foreign economies, it will be necessary for U.S. stakeholders to find more effective ways of working with each other. In policy terms, this means that we need a mechanism to build consensus and implement strategy on an ongoing basis, as well as to remove unnecessary obstacles to cooperation that exist in the United States.

The committee considered several alternative mechanisms for developing a shared vision for U.S. aircraft industry development and for providing a continuing focus for the associated tasks identified above (developing investment and R&D incentives, identifying critical technologies, assessing international technology transfer, and developing guidelines for these transfers). One possibility would be to charge NASA or another existing agency with the task. Indeed, until it was reformulated as NASA and given responsibility for leading the space program, the main task of the National Advisory Committee for Aeronautics (NACA) was to perform R&D and provide research infrastructure to ensure U.S. leadership in aviation. In terms of the circumstances that exist today, the major disadvantage of reconstituting NACA, charging NASA with the task, or undertaking some other form of government reorganization are that more than a redirection in R&D policy is necessary, and the policy questions come under the purview of a number of agencies. Existing private sector committees such as the NASA Advisory Council or the Defense Science Board that advise individual agencies on their R&D programs could perform specific tasks

[13]For a comparison of the approaches taken by Japanese and U.S. aircraft suppliers in the face of

related to developing a U.S. vision. However, these existing advisory
tees share with their corresponding agencies a lack of breadth that con
compelling reason for not designating one of them as the focal point.

Another alternative would be for the Aerospace Industries As
(AIA) to play a leading role, perhaps in combination with other indus
ciations. AIA conducts ongoing technology road map activities for the
and can be expected to make further contributions toward addressing t
raised in this study. There are, however, other factors that argue agai
dustry association serving as the focal point for formulating a shared v
undertaking the associated tasks. In addition to incorporating a wide
industry views—including suppliers—private sector input to this pro
need to incorporate viewpoints and expertise outside of the industry in
represent the broader national interest.

A final alternative would be an industry-government committee s
the National Advisory Committee on Semiconductors (NACS), which
tablished by Congress with members appointed by the President.[14] NAC
several reports over the years of its existence and disbanded in 1992.
some experts credit NACS with helping to foster a closer industry-go
partnership that has contributed to the resurgence of the U.S. semic
industry, others argue that its effectiveness was limited by political a
factors. Still, some useful insights can be drawn from this mixed ex
Clearly, a private sector advisory group cannot be fully effective in al
government interest in its advice and willingness to incorporate that ad
policymaking.

From the preceding consideration of alternatives, several necessar
teristics for an effective new institutional mechanism can be identifi
should have high-quality industry membership, but not be constitute
ceived as representing a "special interest"; (2) it should be a means t
regularized private sector input on policy questions of an interagenc
preferably delivering that input to a high-level interagency group of
and (3) the effort to develop a shared vision for the aircraft industry
supported by senior government and industry leadership.

In order to accomplish the task of consensus building and strateg
mentation, the committee recommends the creation of a National
Advisory Committee (NAAC) to report to an interagency group of re
government officials. The primary responsiblity of the National Aviati
sory Committee should be to create and further the implementation
tional vision for aerospace industrial development in the United States
of the interagency nature of this responsibility—reflected in many of th
mendations above—the committee suggests that this group report to
tional Economic Council (NEC) or other appropriate group with int

[14]See National Advisory Committee on Semiconductors, *A National Strategy for Sem*
(Washington, D.C.: U.S. Government Printing Office, 1992).

responsibilities. The White House is already leading an interagency effort to reassess U.S. aeronautics and space policies, the effectiveness of which could be enhanced by regularized private sector input.[15] The NEC should take advantage of this existing effort in forming NAAC. As a channel for building private sector consensus on policy issues related to aircraft manufacturing, and by providing guidance for the wide variety of agency activities that affect the industry, NAAC would be a focal point for developing a shared vision and an effective strategy for the U.S. aircraft industry.

The National Aviation Advisory Committee would be composed of knowledgeable leaders from industry, academia, and elsewhere who could represent the national interest. Senior members of the government could attend meetings of this advisory committee in an ex officio capacity. To be effective, such a committee would need the full cooperation of the critical industrial sectors of the aircraft industry, including the lower-tier suppliers. NAAC could function well with a staff of two or three professionals detailed from industry or government agencies with responsibilities in aeronautics. The activities of NAAC could be reviewed periodically, and its agenda restructured as appropriate. The overall objective must be to maintain the leadership position of the U.S. aircraft (and its supplier) industry, and to maintain a strong domestic engineering and manufacturing base.

Besides developing a shared vision, other necessary tasks have been enumerated above: suggesting changes in tax and other policies to encourage capital investment and R&D by U.S. aircraft manufacturers, identifying critical technologies, developing guidelines for international technology transfer, and assessing international technology flows. As part of its mission, the National Aviation Advisory Committee should further the implementation of the other key recommendations made above, including new policies that promote rather than discourage civil-military integration, as well as greater commitment of resources and focus in government R&D programs on product-applicable aerospace technologies.

The National Aviation Advisory Committee should also be specifically charged with generating recommendations for policies to achieve balanced international flows of technology and symmetrical access. This task is central to continuing U.S. leadership in the global aerospace industry. In the past, Japan has utilized mandatory technology transfer to strengthen the technology base of its industries and enable companies to compete in global markets. Working with both U.S. primes and suppliers, NAAC should stimulate the development of new approaches—including incentives for transferring and utilizing technology from abroad—that advance the collective interests of the U.S. aircraft industry vis-à-vis the Japanese and other global industries.

A further important task is the removal of unnecessary barriers to cooperation between companies. In recent years, laws and regulations have moved in a

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[15] "Washington Outlook," *Aviation Week & Space Technology*, September 27, 1993, p. 21.

# The Importance of the U.S. Aircraft Industry

track record of the U.S. aircraft industry over the past fifty years con- one of the outstanding success stories of global competition. This nd the importance of the aircraft industry to America's economic well tional security, and technological leadership are testified to by numer- ts and experts.[1] The economic importance of the industry can be seen the relevant statistics. The U.S. aerospace industry holds more than e world market and ranks sixth among U.S. industries in total sales.[2] U.S. aircraft sales were $72.8 billion, and the combined trade surplus ransports, engines, and parts was $23.7 billion.[3] Table A-1 contains a

National Research Council Aeronautics and Space Engineering Board, *Aeronautical es for the 21st Century*, (Washington, D.C.: National Academy Press, 1992), p. 1; Council tiveness, *Gaining New Ground: Technology Priorities for America's Future*, (Washington, cil on Competitiveness, March 1991), pp. 55-56; Michael L. Dertouzos, Richard K. Lester M. Solow, *Made in America: Regaining the Productive Edge* (Cambridge, Mass.: MIT ) pp. 201-216; and U.S. Congress, Office of Technology Assessment (OTA), *Competing America, Europe and the Pacific Rim* (Washington, D.C.: U.S. Government Printing 1), pp. 341-358.

aerospace market is divided into several segments, including aircraft, missiles, space, and ducts and services. U.S. Department of Commerce, *U.S. Industrial Outlook 1993* n, D.C.: U.S. Government Printing Office, 1992), pp. 20/1-20/3.

space Industries Association (AIA), "1992 Year-End Review and Forecast—An Analysis," 992. Note that AIA figures are somewhat different from the Department of Commerce pearing in Table A-2.

Pratt & Whitney in negotiations with the Japanese government on the HYPR program. U.S. antitrust laws and enforcement must continue to move toward a recognition that competition in many high-technology industries—particularly the aircraft industry—is global. Collaboration at the U.S. industry level should be permitted and extended to the supplier level in order to conserve resources in technology and program development, to respond quickly to global market needs with superior products, and—perhaps most important in the context of this report—to allow individual firms to work together when appropriate in bargaining with potential foreign partners so that they and the U.S. economy as a whole maximize the benefits of international collaboration.

*Recommendations*

- In order to implement the steps outlined here and provide an ongoing focus for strategy building for the U.S. aircraft industry, the committee recommends an independent National Aviation Advisory Committee be established by the National Economic Council.

| | Japan | [illegible] |
|---|---|---|
| general aviation aircraft | 13,381 | 580,243 |
| ...ary aircraft | 100,976 | 1,909,395 |
| helicopters | 11,783 | 11,294 |
| passenger and cargo aircraft over 15,000 kg | 2,574,413 | 22,375,036 |
| parts and equipment not elsewhere | | |
| or included | 1,089,140 | 10,140,951 |
| and military aircraft, balloons, gliders | 1,081 | 13,415 |
| ...ised Civil and Military Piston Engines and Parts | 1,777,348 | 415,754 |
| ...ised Civil and Military Turbine Engines and Parts | 149,172 | 636,220 |
| ...pace vehicles, and parts | 245,182 | 1,764,678 |
| ...ced civil and military aircraft engines and parts | 166,519 | 5,683,953 |
| ...ised civil and military aircraft | 2,203,850 | 26,119,219 |
| | 9,152,854 | 70,970,807 |

U.S. Department of Commerce.

...dustries and contribute to the overall economy.[1] U.S. strength in the ...ment and production of transport aircraft is also an important support ... defense industrial and technology base. Technology developed for ...cial transports is often utilized in military programs; the production of ...cial aircraft reduces military aircraft costs in companies that ...cture both; and commercial aircraft production helps to maintain the ... and the work skill base in times of weak military demand.[2] Finally, the ...ce of American-made aircraft has long played a major role in ...ng the safety and efficiency of the nation's air transportation system.

...e aircraft industry—like many others—is regionally concentrated, so ... economic importance is felt unevenly throughout the country.[3] In

...se technologies include "system integration in the design and manufacture of complex, high- ...ce equipment; project management to meet demanding targets for performance, cost, and ...; sophisticated manufacturing techniques for fabrication, testing, and assembly; and computer- ... manufacture, factory automation, and large-scale integrated information processing" as well ...more obvious ones that affect aircraft performance—aerodynamics, propulsion, advanced ... and avionics and control . . ." National Research Council, *The Competitive Status of the ... Aviation Manufacturing Industry* (Washington, D.C.: National Academy Press, 1985), p.

...A, op. cit., p. 344.

...ording to Boeing Commercial Airplane Group's brochure, "The Invisible Exporters," ...987 and 1991 the Boeing Material Division procured an average of $10 billion per year in ... services from suppliers in all 50 states. More than three-quarters of this amount was ... from suppliers in four states: Ohio, California, Connecticut, and Washington. Of course, the ...t-tier suppliers in these states made purchases of their own, likely resulting in a greater ... dispersion (including from overseas) at lower tiers.

sales. Table A-3 lists aerospace export figures for 1992. Table A-4 indicates aerospace trade with Japan.

The aircraft and aerospace industries are also key components of America's larger technological enterprise. The aerospace industry accounts for about one-quarter of U.S. industrial R&D expenditures. Many of the technological competencies fundamental to competitiveness in transport aircraft diffuse to

**TABLE A-1** 1992 Industry Comparison—Aerospace and Chemicals

| | Aerospace (aircraft) | Chemicals |
|---|---|---|
| Value of shipments | 125.7 (54.0) | 301.9 |
| Share of gross domestic product (%)[a] | 2.1 (1.0) | 5.0 |
| Employment[a] | 695,000 (253,000) | 853,000 |
| Imports | 12.7 (5.9) | 25.1 |
| Exports | 42.2 (24.0) | 44.2 |
| Trade surplus | 29.5 (18.1) | 19.1 |
| 1989 R&D spending | 26.3 | 11.5 |
| 1990 non-federally financed R&D spending | 6.1 | 12.5 |
| 1990 non-federally financed R&D spending (% of sales)[a] | 3.5 | 5.7 |

[a]Except for these items, all figures are current billion dollars.

SOURCE: U.S. Department of Commerce, *U.S. Industrial Outlook 1993* (Washington, D.C.: U.S. Government Printing Office, 1992); National Science Board, *Science and Engineering Indicators: 1991 Edition* (Washington, D.C.: U.S. Government Printing Office 1991); and National Science Board, *The Competitive Strength of U.S. Industrial Science and Technology: Strategic Issues* (Washington, D.C.: U.S. Government Printing Office, August 1992).

ts to Japan | 3,907
xports to U.S. | 661

Aerospace Industries Association, *Aerospace Facts and Figures 1992-1993* (Washington, 1992), p. 122.

to other high-technology sectors in which the globalization of markets mological capabilities has prompted companies to multinationalize, manufacturers—at least at the level of airframe integrators and manus of major subsystems such as engines and avionics—have generally *not* ned their own offshore production and R&D sites.[1] The globalization of on and design has proceeded largely through international strategic s, consortia, and other types of supplier-partner relationships between ly based companies.

hough U.S. companies continue to hold global leadership overall and in portant industry segments, the transport aircraft industry—including integrators, engine makers, manufacturers of major avionic and strucmponents, and the broad supplier base—faces a number of significant es that threaten this leadership (see Table A-5). Global competition is ving—most notably in the large transport airframe market, where the ndustrie consortium has leveraged significant support from four Eurovernments to gain a large share of the market.[2] Also, as a result of g defense budgets in the United States and elsewhere, fewer resources lable from military programs for R&D, training, and other investinvestments that have traditionally provided an indirect support to cial product development. Further, the synergy between commercial ense R&D has declined in recent years as military aircraft design igly emphasizes features such as stealth, high maneuverability, and ld landing capability. Finally, the global market for large commercial

e difficulty governments face in determining what constitutes a domestic firm, and therefore panies are eligible for public support, is not a problem in this industry. 'There is little foreign stment in the aircraft business.'" George Eberstadt, "Government Support of the Large al Aircraft Industries of Japan, Europe, and the United States," contractor document for the Technology Assessment, May 1991, p. 11.

Gellman Research Associates, Inc., *An Economic and Financial Review of Airbus Industrie*, 4, 1990. The European Airbus consortium members and their respective governments have the indirect benefits that accrue to the U.S. aircraft industry from the defense budget are to the direct government support that Airbus members have received. The U.S. position is ndirect benefits are not really equivalent and that, in any case, European aircraft makers also ise spillovers. Although a detailed treatment of the protracted U.S.-EC conflict over this issue he scope of this report, a number of the policy issues raised by the conflict and the 1992 U.S.-ent are central to the committee's charge.

TABLE A-3 U.S. Shipments of Aerospace Products (thousand dollars)

| Product Description | 1987 | 1988 | 1989 | 1990 | 1991 |
|---|---|---|---|---|---|
| Aircraft | 36,002,800 | 37,765,100 | 39,531,000 | 46,885,300 | 52,513.5 |
| Military aircraft | 16,862,300 | 15,044,400 | 14,832,900 | 14,108,700 | 15,622.0 |
| Complete civil aircraft | 12,491,743 | 16,019,855 | 17,421,046 | 24,864,289 | 29,780.0 |
| Civil aircraft (fixed wing, powered) | 12,145,669 | 15,453,062 | 17,108,080 | 24,608,896 | 29,550.[illegible] |
| Unladen weight not exceeding 2,000 kg | 308,452 | | | | 596.[illegible] |
| Unladen weight exceeding 2,000 kg but not exceeding 15,000 kg | | | | | 802.0 |
| Unladen weight exceeding 15,000 kg | 11,837,217 | | | | 28,151.[illegible] |
| Helicopters (rotary wing) | 338,182 | 559,284 | 301,809 | 247,298 | 218.0 |
| Other civil aircraft (components and kits) | 7,892 | 6,909 | 11,157 | 8,095 | 10.[illegible] |
| Aircraft Engines and Engine Parts | 18,821,900 | 18,866,700 | 19,903,900 | 21,580,200 | 21,314.[illegible] |
| Aircraft engines for military aircraft | 4,205,600 | 3,214,200 | 3,342,000 | 3,265,800 | 2,967.[illegible] |
| Complete civil aircraft engines | 2,841,150 | 3,753,689 | 4,358,246 | 5,335,475 | 5,778.[illegible] |
| Turbojet and turbofan | 2,637,638 | | 4,082,669 | 4,949,573 | 5,465.[illegible] |
| Turboshaft, turboprop [illegible] | 203,512 | | 275,577 | 385,902 | 312.[illegible] |
| [illegible] | 0 | 0 | 0 | 0 | |
| [illegible] | 19,528,900 | 20,545,400 | 21,294,500 | 23,081,800 | 25,288.[illegible] |
| Aircraft parts and auxiliary equipment [illegible] | 15,817,800 | 16,371,000 | 18,155,900 | 19,618,100 | 22,155.[illegible] |
| Aircraft propellers and helicopter [illegible] | 724,100 | 676,300 | 746,500 | 881,100 | 951.[illegible] |

SOURCE: U.S. Department of Commerce.

**TABLE A-3** U.S. Shipments of Aerospace Products (thousand dollars)

| Product Description | 1987 | 1988 | 1989 | 1990 | 1991 |
|---|---|---|---|---|---|
| *Aircraft* | 36,002,800 | 37,765,100 | 39,531,000 | 46,885,300 | 52,513,5 |
| Military aircraft | 16,862,300 | 15,044,400 | 14,832,900 | 14,108,700 | 15,622,0 |
| Complete civil aircraft | 12,491,743 | 16,019,855 | 17,421,046 | 24,864,289 | 29,780,0 |
| Civil aircraft (fixed wing, powered) | 12,145,669 | 15,453,662 | 17,108,080 | 24,608,896 | 29,550,7 |
| Unladen weight not exceeding 2,000 kg | 308,452 | | | | 596,9 |
| Unladen weight exceeding 2,000 kg but not exceeding 15,000 kg | | | | | 802,6 |
| Unladen weight exceeding 15,000 kg | 11,837,217 | | | | 28,151,1 |
| Helicopters (rotary wing) | 338,182 | 559,284 | 301,809 | 247,298 | 218,6 |
| Other civil aircraft (nonpowered) and kits | 7,892 | 6,909 | 11,157 | 8,095 | 10,6 |
| *Aircraft Engines and Engine Parts* | 18,821,900 | 18,866,700 | 19,903,900 | 21,580,200 | 21,314,9 |
| Aircraft engines for military aircraft | 4,205,600 | 3,214,200 | 3,342,000 | 3,265,800 | 2,967,6 |
| Complete civil aircraft engines | 2,841,150 | 3,753,689 | 4,358,246 | 5,335,475 | 5,778,4 |
| Turbojet and turbofan | 2,637,638 | | 4,082,669 | 4,949,573 | 5,465,9 |
| Turboshaft (turbo propeller): | 203,512 | | 275,577 | 385,902 | 312,4 |
| Other, including auxiliary power units excluding missile and space engines | 0 | 0 | 0 | 0 | |
| *Aircraft Parts and Auxiliary Equipment Not Elsewhere Classified* | 19,528,900 | 20,545,400 | 21,294,500 | 23,081,800 | 25,288, |
| Aircraft parts and auxiliary equipment, n.e.c. | 15,817,800 | 16,331,000 | 18,155,900 | 19,618,100 | 22,155, |
| Aircraft propellers and helicopter rotors | 724,100 | 676,300 | 746,500 | 881,100 | 951, |

SOURCE: U.S. Department of Commerce.

| | |
|---|---|
| s to Japan | 3,907 |
| ;ports to U.S. | 661 |

Aerospace Industries Association, *Aerospace Facts and Figures 1992-1993* (Washington, 1992), p. 122.

to other high-technology sectors in which the globalization of markets nological capabilities has prompted companies to multinationalize, nanufacturers—at least at the level of airframe integrators and manu- of major subsystems such as engines and avionics—have generally *not* ed their own offshore production and R&D sites.[7] The globalization of on and design has proceeded largely through international strategic , consortia, and other types of supplier-partner relationships between y based companies.

ough U.S. companies continue to hold global leadership overall and in portant industry segments, the transport aircraft industry—including integrators, engine makers, manufacturers of major avionic and struc- nponents, and the broad supplier base—faces a number of significant es that threaten this leadership (see Table A-5). Global competition is ing—most notably in the large transport airframe market, where the ndustrie consortium has leveraged significant support from four Euro- vernments to gain a large share of the market.[8] Also, as a result of ; defense budgets in the United States and elsewhere, fewer resources lable from military programs for R&D, training, and other invest- investments that have traditionally provided an indirect support to cial product development. Further, the synergy between commercial ense R&D has declined in recent years as military aircraft design gly emphasizes features such as stealth, high maneuverability, and ld landing capability. Finally, the global market for large commercial

: difficulty governments face in determining what constitutes a domestic firm, and therefore panies are eligible for public support, is not a problem in this industry. There is little foreign stment in the aircraft business." George Eberstadt, "Government Support of the Large l Aircraft Industries of Japan, Europe, and the United States," contractor document for the echnology Assessment, May 1991, p. 11.

Gellman Research Associates, Inc., *An Economic and Financial Review of Airbus Industrie*, 4, 1990. The European Airbus consortium members and their respective governments have : the indirect benefits that accrue to the U.S. aircraft industry from the defense budget are to the direct government support that Airbus members have received. The U.S. position is ndirect benefits are not really equivalent and that, in any case, European aircraft makers also se spillovers. Although a detailed treatment of the protracted U.S.-EC conflict over this issue ne scope of this report, a number of the policy issues raised by the conflict and the 1992 U.S.- ent are central to the committee's charge.

afflicting the U.S. airline industry—traditionally the largest component of the aircraft industry's customer base.[9]

It is safe to assume that the aircraft industry will retain its economic importance into the next century, despite the current downturn in sales. The global market for air transportation and large transports is expected to grow significantly over the next several decades. Table A-6 shows that much of this growth is likely to occur in Asia. Further, in contrast to declining spillover benefits from defense to commercial markets, the importance of commercial transport manufacturing for maintenance of the defense industrial and technology base is likely to grow, both because fewer companies will be able to maintain extensive R&D operations on the basis of military work alone, and because increasing pressure for cost performance on the military side will require the incorporation of greater commercial discipline. The benefits that accrue to countries with a strong aircraft industry have always been compelling and have justified public policies of direct or indirect support in the United States and elsewhere. Europe, Japan, Russia, China, and other countries are pursuing a variety of policies to promote domestic aircraft manufacturing. The emerging environment for U.S. private and public policymakers is characterized by significant challenges, high stakes, and a complex field of players and interests.

[9]See testimony of Lawrence W. Clarkson, Corporate Vice President for Planning and International Development, The Boeing Company, and testimony of Thomas M. Culligan, Corporate Vice President, McDonnell Douglas, before the Subcommittee on Aviation, Committee on Public Works and Transportation, U.S. House of Representatives, on the "Financial Condition of the Airline Industry," Washington, D.C., February 24, 1993.

| Materials | Structures | Integration | Delivery |
|---|---|---|---|
| Aluminum<br>Composites | Fabrication<br>Subassembly<br>Tooling<br>Machine tools | Engines<br>Avionics<br>Other components | Marketing<br>Financing<br>Certification |

| Materials | Structures | Engines | Avionics & Instruments | Other Comp & Syster |
|---|---|---|---|---|
| Alcoa | U.S. | Pratt & Whitney | Collins (Rockwell Intl) | Hamilton Standard |
| Kobe Steel | Vought | GE | Allied Signal | Allied Signal |
| Hercules | Grumman | Rolls Royce | Honeywell | Menasco |
| Toray | Northrop | | Sundstrand | Sundstrand |
| Yokahama Rubber | Rockwell International | | Tokyo Aircraft Instruments | Cleveland Pneumat |
| Union Carbide | Japan | | Japan Aviation Electronics | Shinko Electric |
| Rohr | MHI | | TRW | Lear Siegler |
| | KHI | | Westinghouse | Kayaba |
| | FHI | | | |
| | ShinMaywa | | | |
| | Japan Aircraft Manufacturing | | | |
| | Airbus | | | |
| | Deutsche Aerospace | | | |
| | Aerospatiale | | | |
| | British Aerospace | | | |
| | CASA | | | |

NOTE: The list of companies under each heading is included for illustrative purposes and is not an exhaustive list.
SOURCE: National Research Council Working Group on U.S.-Japan Technology Linkages in Transport Aircraft.

| | 1972-1981 | 1982-1992 | 1993-2000 | 2001-2010 |
|---|---|---|---|---|
| United States | 35 | 38 | 39 | 31 |
| Europe | 26 | 28 | 25 | 25 |
| Asia-Pacific | 20 | 24 | 27 | 33 |
| Africa-Middle East | 10 | 6 | 5 | 5 |
| Latin America | 5 | 2 | 3 | 4 |
| Canada | 3 | 2 | 2 | 2 |
| Total market (billion 1993 dollars) | 14.8 | 26.1 | 40.9 | 48.7 |

NOTE: Percentages may not total 100 due to rounding.

SOURCE: Compiled from data appearing in Boeing Commercial Airplane Group, *1993 Current Market Outlook*, March 1993, p. 3.5.

# U.S.-Japan Technology Linkages In Airframes And Aircraft Systems

ing the study process, the committee was briefed on U.S.-Japan ion and competition in various segments of the aircraft industry by and other experts. The material here and in Appendix C draws heavily insights of these experts and also incorporates information from d sources when this was available. Through this process, the committee e to gain access to information on linkages that would otherwise be ble. On some points—particularly points of interpretation related to business issues—published sources of information do not exist. should keep in mind that these accounts rely on individual expert nts and interpretations.

## BOEING COMMERCIAL TRANSPORT ALLIANCES WITH JAPAN

ne more than 20 years since the YS-11 program was canceled, Japanese s in the airframe segment have been carried out mainly through s between the heavy industry manufacturers and Boeing. In the Boeing ive, Japan is important as a market, collaborator, and potential tor. As a wealthy island nation, Japan is a highly developed market for

1). Boeing projects that the total commercial jet market in Japan between 199[illegible] and 2010 will be $60.5 billion in 1993 dollars (440 airplanes), second to the U.S. total of $280 billion and ahead of the rapidly growing Chinese marke[illegible] ($41 billion). Japan Air Lines (JAL) is the largest customer for Boeing's larges[illegible] airplane, the 747 (having bought a total of 114); All Nippon Airways (ANA) i[illegible] the largest foreign buyer for the 767 (having bought 82 thus far).

Boeing has procured parts and equipment from Mitsubishi Heavy Industries (MHI), Kawasaki Heavy Industries (KHI), and Fuji Heavy Industries (FHI) since the start of the 747 program in the late 1960s, with MHI and FHI supplying Boeing on the 757 and KHI on the 737. With the 767 program in the late 1970s and now the 777, the Boeing-Japan interaction has moved from one in which the Japanese companies "build parts to specification," to actual design and engineering interaction from the earliest stages of product development. Table B-1 lists the components built by the three "heavies" on various Boeing aircraft; while Table B-2 shows the involvement of other suppliers.

In looking at the U.S. versus foreign content of Boeing aircraft, on average U.S. content is 85 percent by dollar value across all models, and 60 to 70 percent of subcontracted work is given to U.S. firms. The big change over the past 20 years is the main fuselage sections. Northrop builds most of these parts on the 747, whereas most of the fuselage of the more recent 767 and new 777 models is built in Japan. However this has led to only a moderate shift in U.S. versus foreign content because the fuselage does not constitute a large percentage of the value of an airplane. Foreign content of the 777 will be 16.7 percent including engines (12.6 percent not including engines); foreign content is 12.2 percent for the 767 and 14.6 percent for the 757.[1] When describing their participation in Boeing programs, the Japanese companies use figures for percentage of the airframe by value, which are higher.

## 767 PROGRAM

Boeing had worked with the Japanese companies in the late 1960s when they supplied parts for the 747. Discussions concerning closer collaboration on future aircraft started in 1970; the 767 program was launched in 1978 and a contract was signed with the Japanese to supply parts. The first ship sets were delivered in early 1980. In 1991 the two sides renegotiated for a second 500

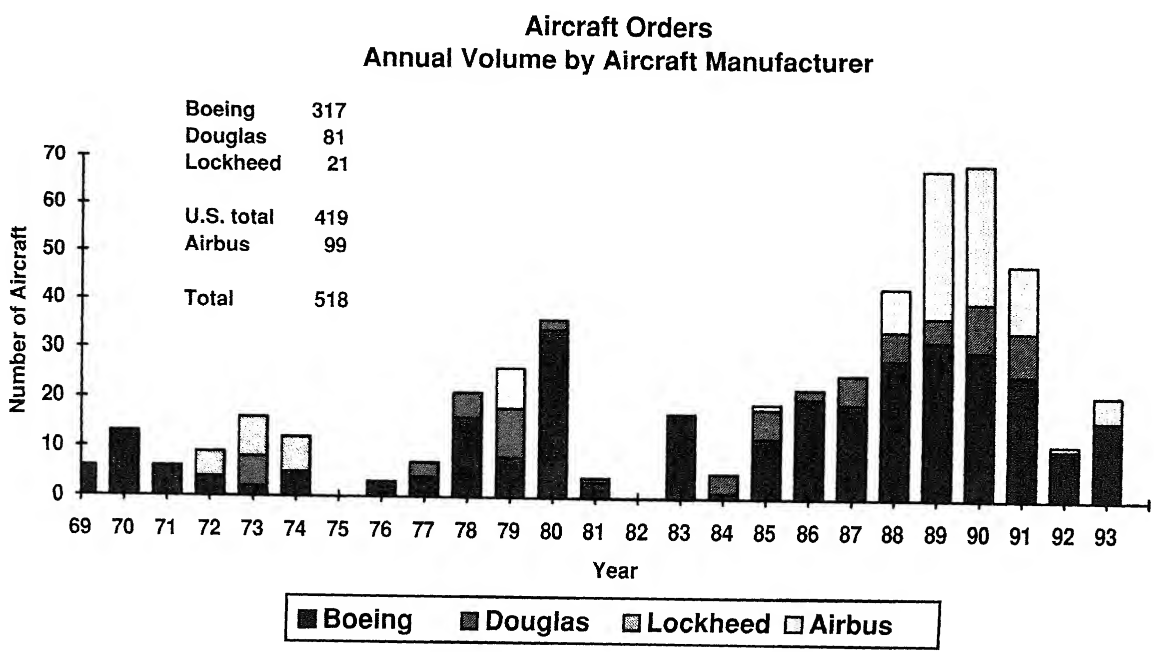
[1]Rolls Royce accounts for the largest share of foreign content. Boeing calculates these figures based on cumulative and projected engine purchases, and uses information provided by suppliers on foreign content of subsystems. It is generally possible to project engine purchases because airlines need to make a significant investment to support the maintenance of a particular engine. It is, therefore, very difficult (but not impossible) for engine makers to dislodge entrenched competition. For example, United generally buys Pratt & Whitney engines, and British Airways generally buys Rolls Royce.

nt on the 767 with Italy's Aeritalia.

67 is a wide-body twinjet that can carry 260 passengers in a mixed-guration. In some versions, the range of the 767 exceeds 6,000 miles. nent was for a fixed-price purchase of the first 500 ship sets, which ed learning curve cost reductions over time. Boeing calculates vork share as 15 percent of the airframe—this does not include ystems and constitutes about 6 to 7 percent of the total value of the This is a nonequity role. The Japanese have taken cost and market have covered their own tooling and other investments. The Japanese it provided funding through success-conditional loans for much of nent. Boeing negotiated using its own production costs as a standard bidding the work out competitively. Earlier procurements from the vere competitively bid, as was some of the work the Japanese do on els outside of these risk-sharing agreements. For example, FHI won vide competition for the replacement of the 757 wing flap.

rst 500 ship sets were not guaranteed, which means that the Japanese assumed the total risk for its work share. The price was fixed in hich means that the exchange rate fluctuations during the 1980s voc with the planning of the Japanese companies. Since the yen d overall, this has put cost pressures on the three heavies. Boeing at at this point the Japanese companies have made money on the 767 verall, but results have varied greatly by year.

g had already made the major design decisions when the 767 deal d with the Japanese. During the detailed engineering stage of the apanese engineering personnel were stationed at Seattle for up to a nology transfer between Boeing and its foreign partners was limited by the hardware choices—Boeing did not give the Japanese ians) sensitive parts of the airframe. Engineering data exchange was on a "need-to-know" basis. The Japanese were given engineering ssary to design their parts through digital data transmission or ape. The Japanese were trained in computerized design techniques. ole transfer of component design technology occurred, but this "old" technology from Boeing's standpoint. Transfer to the hrough program subcontracting probably allowed Boeing a higher this asset than alternate technology transfer mechanisms (such as would have, and the business arrangements were competitive.



Aircraft Orders
Annual Volume by Aircraft Manufacturer
Boeing 317
Douglas 81
Lockheed 21
U.S. total 419
Airbus 99
Total 518
Number of Aircraft
70
60
50
40
30
20
10
0
69 70 71 72 73 74 75 76 77 78 79 80 81 82 83 84 85 86 87 88 89 90 91 92 93
Year
Boeing
Douglas
Lockheed
Airbus

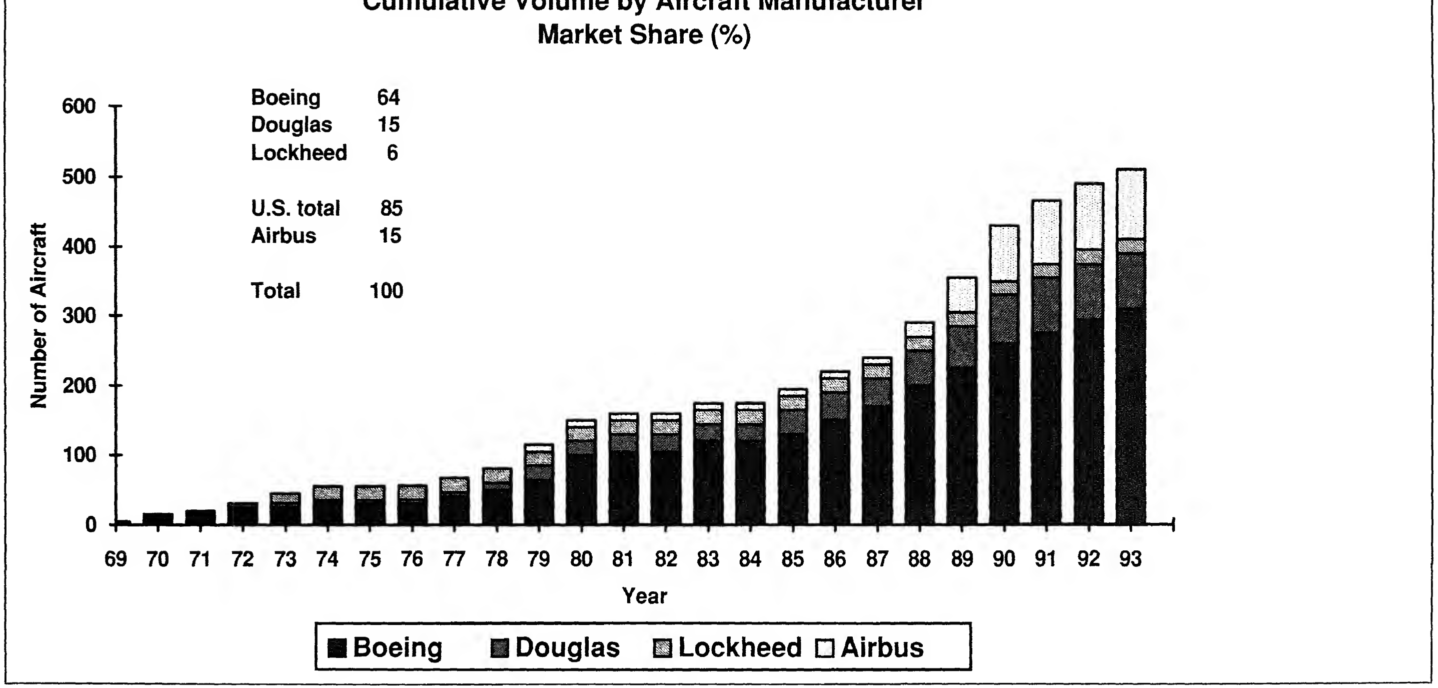



**FIGURE B-1** Japan aircraft orders. SOURCE: GE Aircraft Engines.

**TABLE B-1** Japanese Three Heavies: Boeing Involvement

| Mitsubishi | | Kawasaki | | Fuji | |
|---|---|---|---|---|---|
| 747 | • Inboard trailing edge flap | 747 | • Outboard trailing edge flap | 747 | • Aileron<br>• Spoiler |
| 767 | • Section 46 fuselage panel<br>• Entry and cargo doors | 767 | • Sections 43 and 44 fuselage panels<br>• Wing inspar ribs | 767 | • Wingbox fairing<br>• Mlg. door |
| 757 | • Stringers | 737 | • Wing inspar ribs | 757 | • Outboard flaps |
| 777 | • Section 46 body panels<br>• Passenger and bulk cargo doors<br>• Section 48 tailcone | 777 | • Section 43 body panels<br>• Section 44 body panels<br>• Section 45 keel beam<br>• Section 12 wing inspar ribs<br>• Cargo doors | 777 | • Section 11 wingbox<br>• Sections 11 and 45 integration<br>• Section 49 wingbox fairing<br>• Mlg. doors |

SOURCE: Boeing.

**TABLE B-2** Japanese Aerospace Industry Involvement in Boeing Programs

| *Manufacturing* | *Representative items and activities* | *Programs involved* | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | 707 | 727 | 737 | 747 | 757 | 767 | 7J7 | 777 |
| Japan Aircraft Manufacturing Co. | Structural components | | | | | x | (x) | | |
| ShinMaywa Industry Co. | Structural components | | | | | (x) | x | | x |
| Japan Aircraft Manufacturing Co. | Galleys, lavatory modules | | x | x | x | x | x | | x |
| Teijin Seiki Co. | Actuators, servos | | | x | x | x | x | x | x |
| Shimadzu Corp. | Gearboxes, valves, actuators | | | x | x | x | x | | (x) |
| Kayaba Industry Co. | Valves, actuators | | | x | | x | x | x | |
| Yokahama Rubber | Lavatories, honeycomb core products | | | x | x | x | x | | |
| Nippon Miniature Bearing | Bearings, motors | | | | x | x | x | | |
| Mitsubishi Electric Corp. | Valves, actuators | | | | x | x | x | | |
| Matsushita Electric Corp. | Entertainment systems, panel-mounted radio speakers, CRTs | x | x | x | x | x | x | x | |
| Sumitomo Precision Products Co. | Landing gear structures | | | | | (x) | (x) | | |
| Koito Manufacturing Co. | Lights | | | x | x | x | x | | |
| Tokyo Aircraft Instrument Co. | Instruments | | | | x | x | x | | |
| Sumitomo Electric Industries | Fiber optic couplers | | | | | | | x | |
| Suwa Seikosha Co. | Flat-panel displays | | | | | | | x | |
| NEC Corp. | Digital autonomous terminal access communications systems | | | | | | | x | |

*continued on next page*

**TABLE B-2** Japanese Aerospace Industry Involvement in Boeing Programs *Continued*

| *Manufacturing* | *Representative items and activities* | *Programs involved* 707 | 727 | 737 | 747 | 757 | 767 | 7J7 | 777 |
|---|---|---|---|---|---|---|---|---|---|
| Japan Aviation Electronics Industry | Flat-panel displays, air data intertial reference systems | | | (x) | (x) | (x) | (x) | x | |
| Koito Industry | Seats | | | x | x | x | x | | |
| Toshiba Corp. | CRTs | | | | | | | | |
| Showa Aircraft Industry Co. | Honeycomb | | | x | x | | | | |
| Tenryu Industries Co. | Seats | | x | x | x | | x | | |
| Shinko Electric Co. | Motors | | | | (x) | (x) | (x) | | |
| Shin Nippon Koki | Machine tools | | | | | | | | |
| Kobe Steel | Titanium and steel forgings | | | x | x | x | x | | |
| Furukawa Aluminum | Aluminum forgings, extrusions | | | | | x | x | | |
| Daido Steel | Steel | | | | | | x | | |
| Toshiba Machine | Machine tools | | | | | | | | |
| Sony Corp. | Entertainment systems | | | | | | | | x |

NOTE: (x) Significant indirect participation.

SOURCE: Boeing.

7J7/YXX

ext Boeing-Japan collaboration was on the 7J7 program, also known X in Japan. A memorandum of understanding (MOU) was signed in irming Japanese participation as an equity partner in the development -seat short- to medium-range twinjet. This project would have l a significant increase in the Japanese role over the 767. The through the Japan Aircraft Development Corporation, would have ercent of the equity and would have been involved in all phases of oduction, and marketing. When the 1986 MOU was signed, the deal considerable attention and some criticism.[2] Boeing argued that for reated in Japan by the program, 23 would be created in the United ie to the subsequent shelving of the program, the collaboration o a lower profile. As in other collaborative international programs, nment approvals—such as a Department of Commerce technical data ense—were needed for this project. The Departments of Commerce se tend to take a restrictive stance on certain technologies such as ed to composites, but sensitivity is generally limited to design know- than manufacturing processes.

ive discussions about market projections and other areas were start up the 7J7 relationship. A collaborative research program also d, with Boeing sharing some summary data from its generic subsonic nd the Japanese companies sharing data from the work they were National Aerospace Lab and internally in fluid dynamics and the new composite materials, flaps, and slats. Boeing sees high-speed ics as the fundamental technology to protect, and there has been no on with the Japanese in high speed.

ugh some support is still provided by the Japanese government, the m has not yet been launched, and the short-term prospects are not y favorable. The market for the 150-seat aircraft has not coalesced. end, it overlapped with Boeing's existing 737; at the high end, with wo technical developments outside of the Boeing-Japan negotiations enced this course of events. First, Boeing wanted to utilize an an turboprop engine, which it was working on with GE and which ver significant gains in fuel economy.[3] However, falling fuel prices in d late 1980s made fuel economy a less critical concern for airlines. contrary to earlier expectations, Boeing was able to extend the life of fitting it with high bypass engines. The company had thought that

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B. Reich, "A Faustian Bargain with the Japanese," *The New York Times*, April 6, 1986, 2.

C. Mowery, *Alliance Politics and Economics: Multinational Joint Ventures in Aircraft*, (Cambridge, Mass.: Ballinger Publishing Company, 1987), p. 73.

Because of the success of the extended 737 and prospective competition fro the Airbus A320, a brand new airplane in the 150-seat class was much le compelling strategically for Boeing. More recently, Boeing has decided develop an advanced version of the 737, pushing development of an all-ne aircraft in that market segment further into the future.[5]

Both Boeing and the Japanese had put a significant amount of money in the program, and there is still a strong incentive for the Japanese not to let formally die. The 7J7 continues to command a line item in the budget of t Ministry of International Trade and Industry (MITI). Low-level technic collaboration continues, but closer cooperation was delayed until the next maj Boeing program, the 777.

## 777

Boeing, the three heavy industry companies, and the Japanese governme worked out a "program partnership" for the 777 twinjet, which is due to ent airline service in 1995 and will seat 328 with a range of 5,000 miles in i initial version.

The structure of the deal itself is very similar to the 767, although Boeir originally offered equity participation similar to that contemplated for the 7J While the Japanese were interested in an equity share, Boeing set a minimu amount, and the Japanese were not prepared to assume a risk of that size. Th 777 is a much larger airplane than the 7J7 was conceived to be, wi correspondingly higher development costs. Development costs for an all-ne jet such as the 777 are estimated to run about $5 billion.[6] As an equity partne the Japanese heavies would be participating at a significantly higher level, an the business justification had to be compelling to their top management Apparently, the companies were not willing to assume that great a risk, despi some apparent pressure from the government to do so.

The Japanese ended up with nonequity participation and some increase i their role compared to the 767. There are differences between the tw programs, the most obvious being increased Japanese work share. Boein calculates that on the 777, the heavies are building 20 percent of the airfram

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[4]George Eberstadt, "Government support of the Large Commercial Aircraft Industries of Japa Europe, and the United States," contractor document for the Office of Technology Assessment, Ma 1991, p. 74.

[5]As this report was being prepared, possible Boeing-Japan collaboration in the 737-X and YS- programs was the subject of press reports. The Japanese government has supported research for number of years on the 80 to100-seat YS-X transport, with the intention of eventually launching program led by Japan with foreign participation. See Eiichiro Sekigawa, "Japan Mulls Joining 737- Wing Project," *Aviation Week and Space Technology*, July 26, 1993, p. 32; and Jeff Cole, "Boein May Aid Japan Suppliers in Building Jet," *Wall Street Journal*, September 8, 1993, p. A3.

[6]Jeremy Main, "Betting on the 21st Century Jet," *Fortune*, April 20, 1992, p. 102.

in a contract for a fixed number of ship sets, the 777 agreement is in the life of the program.

Japanese are also more involved in designing the components that they facturing. There were many more Japanese engineers involved in 777 ent than in 767 development, with several hundred sent to Seattle e most intensive design phase. Yet, as with the 767, the Japanese are n the engineering effort to their own work package. Structural and the software and models needed to obtain results—are not shared, end results necessary for the Japanese to design the parts they will example, Japanese engineers had access to the load data for the wing ction because they designed and will manufacture the wing box, but he outboard section were not made available. The most significant to the Japanese work share are the 777's wing box and the pressure both of which were designed and built by the heavies. Both are nd somewhat tricky to manufacture, but they do not constitute d technology" from Boeing's perspective.

777 is introducing several significant technical advances. The CATIA ensional computer design system was used to make the design process rless" as possible. CATIA was originally developed by Dassault of France, but Boeing has also made proprietary improvements. The ct of CATIA will be known as the first aircraft are built and delivered. ess has not saved on the number of engineers needed to design the but the hope is that it will cut down on the number of design ions that have to be made after production begins. Boeing estimated uld have 50 percent fewer modifications on the 777 than on the 767. s written, Boeing was running at the rate of 10 percent of 767 -a 90 percent improvement. The value of CATIA will be in the of recurring costs by eliminating a significant percentage of the omalies that normally require correction during production of the first ship sets. In addition to CATIA's role in streamlining the design the availability of design data in a digital form has enabled ble manufacturing advances. This is discussed in more detail below.

ugh a system of passwords, the access of Japanese engineers on-site ing at the computer system in Japan that Boeing set up for the 777 limited. The CATIA design software itself is "locked up," as is work of the airplane unrelated to the Japanese work share. Attempts to get e system would set off alarms. Japanese engineers went through a TIA user's course, which takes about a week. Because the Japanese ccess the software, it would not be possible for them to make nents on CATIA in conjunction with the 777 program.

ite, the visiting Japanese engineers were given access only to certain , and sensitive manufacturing sites were accessible only with a Boeing

within Boeing, analysis and testing of the design are done by a separate grou of engineers from those who work on design with the Japanese heavies. It i fairly straightforward to segment information on a need-to-know basis eve within the company. Boeing provided a briefing to engineering an manufacturing personnel who would come in contact with the oversea partners, conveying the basic message that they should provide only wha would be needed for the partners' work share. A management committe reviewed and decided on questions that arose in gray areas.

As in any program of this size, various management issues came up durin the negotiations and design process. For example, after Boeing had determine how much work to give the heavies, the Japanese partners needed to reac agreement on dividing the work share. Apparently, this process was nc completely straightforward. Also, once work got under way, the engineerin resources of the heavies were stretched by the simultaneous demands of 77 and FS-X design work. Although the quality of the Japanese engineering effo was always outstanding, some adjustments were necessary during the desig phase to keep the program on schedule. Also, from the Japanese perspective the dispatch of large numbers of engineers to Boeing became quite expensive The heavies would prefer to conduct as much of the interaction as possibl within Japan in order to minimize travel and expatriate living expenses.

From a business and program development point of view, the partnershi with Japan on the 777 has been very beneficial for Boeing. Since the produc has not been introduced and its success in the market is not yet known, it i difficult to measure the bottom-line benefits, but order information thus far i promising. All three of the major Japanese airlines have ordered the 777.

Boeing's policy is to limit dependence on suppliers in the structures an airframe area (as opposed to the engine and avionics areas, where the breadt of technology is so great that the company has no choice but to be dependent) Boeing maintains the capability to manufacture all the components it buys fror the Japanese. MITI has recently told Boeing that it wishes to encourag manufacturing technology transfer from Japan to the United States and ha offered its assistance. Because of Boeing's relationship with the heavies, it i largely aware of what happens on the manufacturing side, and it reports n difficulties in obtaining access to technologies improved upon by Japanes partners. For example, one of the Japanese companies had developed a roboti skin polisher and responded positively to Boeing's request to license it. Anothe example is the method of laying up thick composite structures that Boein learned from FHI in conjunction with the latter's work on the 767 main landin gear door. Boeing had been running structures of that size through th autoclave three times. FHI developed a method of laying up the composit material that required only two runs through the autoclave.

was interested in developing a second source, and Toray did license its technology to a U.S. firm, but in the end a competitive U.S. bid did rge. As a "next best" solution, Toray has built a facility in the Puget egion to supply Boeing.

## Japanese Advanced Manufacturing Capabilities

ing its study mission to Japan in June 1993, the committee had an nity to tour the manufacturing facilities of the Japanese heavies and smaller aircraft suppliers. The committee was particularly impressed : manufacturing capabilities of Japanese industry—much of it devoted cipation in the 777 and other Boeing programs. Here are selected :s of advanced aircraft manufacturing capabilities possessed by one or the heavies:

*'uselage panel drilling and riveting:* In addition to its utility in the process, CATIA allows for significant manufacturing process advances. g the design data base to run manufacturing processes, much of the that has traditionally been necessary for aircraft manufacturing can be ed. Using CATIA in conjunction with numerically-controlled machine improve processes was inherent in the system from the beginning, but nese have significant latitude in designing their own processes along panese or foreign machine tool makers. Processes that the Japanese for the 777 must be approved by Boeing.

: Japanese have realized much of CATIA's potential in driving cturing in the fuselage panel drilling and riveting processes. Particularly ve is the use of pogo sticks to support aluminum skins in drilling and fuselage panels. The height and angle of the sticks as well as the hole s are set according to the CATIA data base for particular panels. In to eliminating tooling, this reduces manufacturing cycle time and s quality.

*'reparing aluminum skins:* Preparation of the aluminum skin for the equires chemical-milling of the panel around the window openings. g for the chemical-milling is prepared on a new large-scale numerically ed five-axis, carbon dioxide laser that cuts a rubber mask laid on the 'his machine also operates from the CATIA design data base. After l-milling, the skin is stretch formed to take the radius of the fuselage nen trimmed and polished on another five-axis robotic machine.

*'rocesses for thick aluminum parts:* Although the aluminum skins used y parts of the fuselage are thin enough to be shaped through chemical and stretch forming, some of the thicker parts would be made more ble to wear if this method were employed. Instead, thicker parts are

machines. To shape the curvature of the wing center section skin, a special machine generates the curved shape by shotpeening the skin in a controlled process while simultaneously shotpeening the surface for fatigue strength.

The machines used to mill the wing stringers are very high-speed, numerically controlled horizontal mills, about 15 feet long, that shape the stringers from a solid bar of aluminum. The wing spars are also milled on a universal five-axis numerically controlled machine.

*4. Composites manufacturing:* The Japanese heavies have made significant investments in composites manufacturing. Some of these are related to non-Boeing programs (such as the FS-X). Several Japanese companies possess the latest equipment to do immersion ultrasonic inspection of very large-scale composite aircraft structures. The equipment is also numerically controlled with automatic recording of inspection data, and is designed to detect subsurface flaws or lack of bonding in the composite structures. On the engineering side, the committee saw some excellent work being done on composite cloth configurations aimed at solving the fundamental problem of delamination in composite structures.

The overall impression is that various fundamental technologies have been distributed among the major players in the Japanese industry. From manufacturing processes involving fuselage structural components, to more highly loaded structures such as wing sections, to lightweight composite structures, which include moderately stressed composite landing gear doors as well as more highly loaded carbon fiber wing structures, Japanese aircraft manufacturing capabilities are state of the art.

The heavy investment in the most advanced robotic numerically controlled machines is clearly aimed at gaining a leadership position in high-quality, low-cost manufacturing. Although quality and manufacturing cost have always been a high priority in the U.S. aircraft industry, along with leadership in aerodynamics and systems integration, the committee gained a clear impression that the Japanese have placed a very high priority on winning in the arena of manufacturing quality while achieving cost leadership.

## Boeing Manufacturing Capabilities

A subgroup of this committee also had an opportunity to visit several of Boeing's Washington State facilities that will manufacture the 777. During the past three years, Boeing has invested in excess of $2 billion in new factories, equipment, and office facilities aimed at achieving a quantum improvement in product quality and manufacturing productivity. This description of Boeing's capabilities is included to illustrate the scale of investment and types of advanced manufacturing technology currently required to stay competitive in the aircraft industry, to balance the discussion of Japanese capabilities, and to

ts required for final aircraft assembly. The operation starts with buildup
; and wing skins using the latest robotic riveting and bolting equipment. are four huge fixtures for final assembly of left-hand and right-hand ections. Fuselage barrel sections are assembled from panels supplied by anese heavies in huge "rollover" fixtures that permit access to assembly floor beams, with the floor assembled overhead and the barrel section 180 degrees from its normal position. The floor beams are carbon fiber ite structures, the first such application of composites in Boeing rcial aircraft. The first 777 was rolled out on April 9, 1994, with plans nence flight tests in June 1994.

e Auburn sheet metal shop is another new facility in which up to 10,000 it structural components, from simple brackets to the huge hydroformed that connect the wings through the wing box, are manufactured. es include very large, new, horizontal milling machines for cutting e elements of complex geometric shapes. The machining center is er driven from dispatch of raw material through delivery of finished The machining instructions are contained on compact discs that are l in the machine by the operator. The plant contains some of the world's hydroforming and stamping equipment.

ese investments will likely enable Boeing to achieve major ements in cycle time. Previously it took an average of 40 days to process rom order input to product output. Today it takes about nine days, the ve being a five-day cycle. Current efforts are focused on reducing product ity by using techniques such as statistical process control.

e Fredrickson wing spar and skin mill facility is also new. In this plant r huge wing skin milling machines with vacuum milling beds up to 210 length. Each machine is capable of milling two wing skins neously. In addition, there are similar special milling machines for ing the wing spars. The plant includes special facilities for shotpeening rs and edges of the wing skins, automated anodizing, and painting. The elivers the complete wing skins and spars to the Everett facility, where g skin-spar assembly is completed.

eing has also made significant investments in composites manufacturing ty at Fredrickson. The facility includes four large-scale tape lay-up es, with the entire process carried out in an atmospherically controlled e-pressure) building. Two new 40-foot-diameter autoclaves, with front r door loading, are operational. All trimming and cutting operations are y a computer-controlled water jet cutter. The compound curved es are supported on a pogo stick bed driven by the CATIA data base.

be a major player in aircraft, and that it is preferable for the major firms to be teamed with Boeing rather than allied with one of Boeing's rivals or mounting an independent challenge. The Japanese have not collaborated in a significant way with either Airbus or McDonnell Douglas on commercial transports, and have not become an independent force thus far. Airbus has been actively looking for Japanese participation in its programs. The Eurpean consortium has sold A320s and A340s to ANA, with ANA obtaining important European landing rights at about the same time. Kawasaki has one contract for the A321, which is the first supply contract between one of the heavies and an Airbus partner.

Boeing has received high-quality components delivered on time at a price that U.S. suppliers would be very hard pressed to beat. The risks assumed by the Japanese (in the form of success-conditional loans by the government and the companies' own investments) have allowed Boeing to avoid the high financial leveraging necessary for earlier projects like the 747. The Boeing relationship has provided the Japanese heavies with a relatively low-cost, low-risk means of entering the global airframe field. Participation in Boeing programs—particularly the 777—has allowed the Japanese heavies to implement advanced manufacturing techniques in producing modern technology aircraft, but they have not obtained Boeing's most critical technologies.

Perhaps the most critical technology in design is knowing how to make the end product do what it is supposed to do on paper. This is a very difficult process, one that even established players find daunting. Boeing's track record is quite strong in this area. Because the engines are a critical determinant of performance, Boeing audits the engine makers to assess whether new products are likely to meet targeted performance specifications and then estimates the size of any shortfall. This engine audit process is a part of Boeing's organizational knowledge base. Another closely held management technology is the know-how needed to guide a program through the safety certification process and to interact with the Federal Aviation Administration and air safety agencies of other governments.

Up to this point, the Japanese have been content to continue in the role of risk-sharing supplier. The heavies will likely continue to receive government support for Boeing projects as long as they can show that they are receiving increased work shares with greater technical sophistication. Aerospace is a significant but not overwhelming share of the overall business of the heavies. Defense and commercial aircraft programs must compete for resources with other divisions, and the road to the chairmanship of MHI, KHI, or FHI has not traditionally led through the aerospace division. The companies have not significantly "grown" their aerospace activities—there are perhaps 2,000 to

for commercial work, Japan also faces some constraints as it reassesses term strategy. The Japanese heavies have failed twice in independent s, and it is Boeing's policy not to participate in a program at less than ent equity. Further, significant participation in McDonnell Douglas cial programs might be more costly and risky than continuing with and collaboration with Airbus is problematic because the heavies resumably need to take work share away from the Airbus members ves. In the case of Boeing, the Japanese are largely building ents that Boeing would have contracted out anyway.

ough it is important to recognize the constraints currently facing the aircraft industry, there is still no question that Japan has built a able aircraft technology and business base over the past several Significant changes in the global environment, including the ce of the Russian industry and other new players, may present Japan's industry with opportunities to move beyond existing constraints. capabilities, particularly in manufacturing, will allow its industry to expanding its global role into the next century.

## MCDONNELL DOUGLAS

### Commercial Programs

Donnell Douglas's involvement in Japan stretches back over 40 years. operated a variety of Douglas products (DC-3, DC-4, DC-6, DC-7, DC-10, and MD-11) since 1951. Japan Air Systems (JAS), the major carrier along with ANA, is also a longtime Douglas customer. In , the trading company Mitsui & Co. played a major role in financing ch of the MD-11 program. Yet in contrast to growing involvement by airframe manufacturers in Boeing programs over the past two Japanese firms have remained subcontractors in McDonnell Douglas cial programs.

, even this limited involvement has led to growing Japanese capability ber of structures and components areas, particularly composites. In the 70s, MHI won a contract to supply the metallic tail cone for the DC-10, ow manufacturing a composite tail cone for the MD-11. Also, FHI a composite outboard aileron for the MD-11, which meets the targeted at a cost equivalent to aluminum. Table B-3 shows the Japanese s for the MD-11 program.

Donnell Douglas has had several other collaborative relationships with companies and the Japanese government over the years in aerospace ch as satellite launch vehicles and helicopters. However, the interaction

| | |
|---|---|
| Fuji Heavy Industries | Outboard aileron |
| Nippon Hikoki | Underwing barrel |
| ShinMaywa (through Rohr Industries) | Wing/tail pylon |
| Yokohama Rubber | Portable water tank |
| Teijin Seiki | Elevator activator |
| | Sleet activator |

SOURCE: McDonnell Douglas.

in fighter aircraft is the one most relevant to this study and constitutes a good starting point for a discussion of U.S.-Japan collaboration in military aircraft.

## Military Programs: F-15 Licensed Production

U.S.-Japan licensed production of the F-15 was an important step in the evolution of U.S.-Japan collaborative military programs. As noted earlier, Japanese companies had assembled the North American F-86 in the 1950s, and moved on to the licensed production of the more advanced Lockheed F-104 in the 1960s, and the McDonnell Douglas F-4 in the 1970s. In the mid-1970s, Japan began to consider options for replacing the older fighters in the Air Self Defense Force (ASDF) arsenal. The F-15 was chosen over several rivals mainly because of its weaponry, radar, and other aspects of its technological sophistication as an "air superiority" fighter. This decision and the subsequent licensed production agreement were reached relatively soon after the fighter was first deployed in the United States.

There were early security concerns in the U.S. Defense Department over the transfer of advanced technology through F-15 licensed production. Japan is still the only U.S. ally that has been allowed to produce the aircraft. Concerns about the economic and competitive implications of F-15 technology transfers were raised only after the program was launched.[7] In initially deciding to go forward, the broad strategic and political rationale for Japanese production—primarily a greater contribution to regional security from a more militarily capable Japan—prevailed without a great deal of contention in the U.S. government.

[7]In the original 1978 MOU, there were no provisions for the "flowback" at no charge of technological improvements made by the Japanese. An amended 1984 MOU did contain explicit provisions. See Michael W. Chinworth, *Inside Japan's Defense: Technology, Economics and Strategy* [Washington, D.C.: Brassey's (U.S.), 1992], pp. 109-110.

ere classified as "nonreleasable." The extent of this "black boxing" was han in the F-4 program and, according to some experts, provided a on for Japanese industry to pursue the independent Japanese ient of the country's next fighter in the mid-1980s. Still, the gy transfer was substantial in terms of quantity, and it has been argued evel of technology transferred through F-15 licensed production was an in previous bilateral programs.[8] Table B-4 shows the technologies ed to Japan by McDonnell Douglas in the F-4 and F-15 programs.

h of the technology transfer connected with the F-15 program has ce through commercial licensing and technical assistance agreements individual companies. Although these agreements are subject to U.S. ent export approval, Department of Defense (DOD) program officers McDonnell Douglas are not equipped to stay fully abreast of gy transfers at the subcontractor level. At the government level, industry and government have continued to request technical on connected with the F-15, including releasability requests for gies that the U.S. had provided in black boxes. There was sometimes nent among DOD management over these requests, with the F-15 rogram office inclined to urge denial and higher levels tending to

as often difficult to balance Japan's justifications with concerns about g U.S. design know-how. Economic concerns about the potential for F- ology aiding Japan's commercial aircraft capabilities gained credence ogram progressed. Japan generally justified requests by claiming that of a given technology would speed production schedules, reduce nce times, alleviate parts shortages, and reduce the costs of ing large inventories of spares. Some of these requests were ndable—a number of the U.S.-made components had high failure th repair sometimes requiring shipment back to the United States. companies also reported cases in which American supplier arts either lost orders for spare parts or filled duplicate orders. This y affected the operations of Japan's deployed F-15s and provided an for independent development of the FS-X.

requests for technical information, Japanese delegations, and other sms were often used in attempts to gain information that was only connected with Japan's capability to produce and maintain the When consideration of the next-generation fighter began in the mid- OD officials were also forced to consider whether Japanese requests

initial list of technical data to be made available to the Japanese in the F-15 program, for onsisted of 21 pages listing more than 300 items that in turn consisted of everything from ings and rolls of microfilm to magnetic tapes and boxes of microfiche." Ibid., p. 117.

F-4/F-15 License and Technology Assistance Agreements (LTAA)

- Technical data (excluding design data)
- Technical assistance
- Factory training
- Tooling
- Production test equipment
- Mobile training unit
- Knockdown assemblies
- Follow-on material

F-4 Technologies

- Titanium machining
- Titanium forming
- Wire bundle manufacturing
- Stability augmentation and flight control system integration

F-15 Technologies

- Boron and graphite composite
- Titanium tubing
- Digital multiplex bus system integration
- Limited software development capability
- Fly-by-wire flight control integration

NOTE: No design technology or design data has been transferred.

SOURCE: McDonnell Douglas.

were really motivated by a desire for technology that could aid the development of an indigenous fighter. In some cases, the competitive implications were felt more quickly. Soon after Japan Aviation Electronics (JAE) was licensed to produce Honeywell's ring laser gyro-inertial navigation unit, it began marketing a similar system.[9] In the case of the AP-1 mission computer manufactured by IBM, the American company observed the Technology Research and Development Institute (TRDI) and Japanese corporate R&D programs targeted at developing a domestic mission computer for the FS-X, and decided not to contribute to these efforts by licensing its technology. The Japanese programs proved successful anyway—the FS-X mission computer will be indigenous. These two cases illustrate the difficulties faced by U.S. companies in making licensing decisions in areas where Japanese companies are capable and where government and industry are determined to reduce dependence on foreign suppliers. The potential for short-term licensing income, the competitive implications of technology transfer and other factors must be carefully balanced.

[9]Ibid., p. 121.

ers make similar components for the F-15 and for the Boeing 777.[10] er, many of these Japanese suppliers were already making similar nents for Boeing prior to the launch of the F-15 program. The F-15 work neficial in enabling Japanese suppliers to invest in new equipment more , to make incremental improvements in technology, and to cross-fertilize lities from military to commercial work and from aircraft manufacturing r businesses. This process was aided by the close integration of Japan's y and civilian industrial bases in aircraft.[11] The disagreement among s centers on the ultimate significance of F-15 technology transfers for ercial aircraft competitiveness, as distinct from the benefits presented by rk itself.

e impact is somewhat clearer on the military side. There is general nent that the F-15 experience lifted the confidence of Japan's aircraft y and that Japanese companies receiving technology through F-15 tion were in a better position to supply the subsequent FS-X program. nial of U.S. technology also had an impact. The black boxes provided a for TRDI and industry R&D efforts and motivated Japanese industry to an indigenous FS-X. Still, the difficulties that have been widely reported nection with the development of the FS-X show that the Japanese did not e capability to independently design and develop an advanced fighter h F-15 licensed production. Although the experience lifted the ence of Japanese industry to perhaps unjustifiable levels, subsequent pments have exposed continuing weakness in certain key areas.

## FS-X

veeping conclusions about the FS-X are premature since the development is only now reaching a conclusion, and critical issues such as the actual nance and procurement of the aircraft have yet to be resolved. However, fe to say that the process of structuring this Japan-U.S. codevelopment m marked something of a watershed in Japan's security policies and apan relations.

on after the launch of F-15 licensed production, the Japan Defense y (JDA), the Air Self Defense Force, and industry began considering s for replacing the domestically developed F-1 fighter. Although the F-1

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J.S. General Accounting Office, "Technology Transfer: Japanese Firms Involved in F-15 ction and Civil Aircraft Programs," GAO/NSIAD-92-178, June 1992.

David B. Friedman and Richard J. Samuels, "How to Succeed Without Really Flying: The Aircraft Industry and Japan's Technology Ideology," in J. Frankel and M. Kahler, eds., *lism and Rivalry: Japan and the U.S. in Pacific Asia* (University of Chicago Press, 1993), pp.

process with a presumption in favor of a domestically developed fighter. Increasing domestic content, gaining greater managerial control over the program than was possible in a coproduction arrangement, and controlling costs (costs of licensed U.S. aircraft increased by an average factor of four with each program from the F-86 to the F-15) were all considerations. Perhaps the most important factor was an underlying sense that Japan's position in the aircraft industry was fragile and that passing up domestic development would consign Japan to a follower role forever.[13] However, some Japanese policymakers were more cautious. Even at the early stage—before U.S.-Japan relations became a major factor in the decision—some MITI officials worried about industry overreaching. There was also a general recognition that even an "indigenous" fighter would require significant foreign inputs and technology (engines, systems integration).

Although the process of considering options began in the early 1980s, the U.S. government did not involve itself very extensively. By the time serious feasibility studies were launched in 1986, the momentum in Japan for a domestic aircraft was quite strong. The JDA set specifications that could not be met by existing aircraft, and MHI completed preliminary designs for a domestic aircraft with an unrealistically low estimate of development costs.[14] During 1986, DOD became increasingly concerned with the specifications and low development cost estimates, and began a more aggressive push for the FS-X to be based on an existing U.S. design. The McDonnell Douglas F-18 and the General Dynamics F-16 were the leading candidates. DOD's report in 1987 that the cost of a new Japanese design would be two or three times higher than MHI and JDA estimates gave support to Japanese opponents to the indigenous option in the Ministry of Foreign Affairs and elsewhere. In October 1987, after a heated struggle within the Japanese bureaucracy and in the wake of the Toshiba Machine "incident," the United States and Japan reached an agreement to "codevelop" an FS-X based on the F-16 design.

From the start, the two countries conceived codevelopment differently, making it an attractive political solution but ensuring problems later. The Japanese assumed that a Japanese company would manage the process of developing an indigenous aircraft, with selected foreign technologies incorporated as necessary. The U.S. conceived the joint improvement of an existing aircraft, with a priority on ensuring "flowback" of Japanese technology based on know-how transferred by the United States.

[13] Chinworth, op. cit., p. 148.
[14] Ibid., p. 1[illegible].
[15] Ibid., p. 14[illegible].

more than half of the development costs were slated to go toward
cally developed avionics. A U.S. share of 40 percent would mean that
ould be very little development work left for Japanese companies in
ch as composite wing technology. The MOU was finally signed in late

h the Bush administration coming into office in early 1989,
sional concerns over the FS-X agreement were raised in confirmation
er hearings. Contentious debate over the agreement continued through
ng of 1989, with opponents arguing that F-16 technology transfers
contribute to Japanese competitiveness in commercial and military
to the long-term detriment of U.S. industry; that "off-the-shelf"
e procurement of F-16s would cut the huge U.S. trade deficit with Japan
ldressing Japan's security needs more economically; and that Japanese
l capabilities were not high enough for the flowback provisions to
many benefits to the United States. U.S. proponents argued that
ant U.S. participation in the FS-X program was better than none at all,
panese procurement of unmodified F-16s was not a realistic scenario,
flowback would bring considerable benefits.

the end, congressional opponents were not able to stop the FS-X
ent, but they were able to force DOD to gain a "clarification" of several
nts. First, the Japanese explicitly committed to a 40 percent U.S. work
uring the development phase and to providing access to Japanese-
ed technologies. Second, the denial of several key F-16 technologies—
ng computer source codes, software for the fly-by-wire flight control
and other avionics software—was made explicit. The Japanese had
been counting on getting this technology, but DOD had never allowed
ogy transfer in these areas before—to Japan or any other country.

e clarification exercise probably had little material impact on what
actually transpire during the development phase, but it did serve to
e that U.S. policy toward defense technology collaboration with Japan
o longer be made without considering the economic impacts. The
threw into sharp relief the contrast between the contentious divisions
pan policy in the United States and the much more united front—albeit
me bureaucratic infighting—that Japan presents to the United States in
l negotiations. In addition, the contention left heightened resentment on
es. Many Japanese opinion leaders, in particular, resent codevelopment
ng been forced on Japan by the United States.

e development phase is now nearing completion, and first flight is
d for September 1995. Development was delayed during 1991 and
in part because of sanctions placed on JAE after it was found to have
export controls. Some observers expect that the development phase will

begin in 1994. One complication is possible disagreement over developı ent issues, particularly flowback. The original development MOU defined our areas of nonderived technology, meaning that U.S. companies could lic ise technologies in those areas for a fee, but would be entitled to Japa ese developments in other areas at no charge.[15] Some observers believe that his designation was arbitrary and made subsequent Japanese requests to recla ify other technologies inevitable. In early 1993, news reports indicated that DA was indeed demanding the reclassification of fifty technologies.[16] Althougl he FS-X is politically dormant as this is written, controversy could be reigr ed over the issue of derived versus nonderived technologies or over the produc on MOU.

By keeping in mind the considerable remaining uncertainties, it is pos ble to identify some key questions concerning the implications of the FS-X a U.S.-Japan technology linkage and to catalogue areas in which ana sts generally agree or disagree. The three key issues are as follows: (1) Wha re Japanese aircraft capabilities as illustrated by the FS-X? (2) What will be he impact of technology transfers from the United States to Japan? (3) What is he value of technology transfers from Japan to the United States?

On the first point, it is already evident that the FS-X will not be he "superplane" that the Japanese originally claimed it would be. Some of he technologies that Japan was originally planning to incorporate (canards) lid not perform as well as expected and have been removed from the des n. Despite some attempts to blame the U.S. side for cost and schedule probl s, there is no question that the original Japanese projections of FS-X capabil es were unrealistic and that the hubris evident in the late 1980s has been defl ed to some extent.[17]

The long-term implications of United States to Japan technology tran er are still unclear. Although the source codes and other critical items listed at ve were not transferred, the considerable modification of the F-16 necessitated ne transfer of design and systems integration technology from the United State to Japan—a first in bilateral military programs. Although much of this technol gy is "old," analysts have pointed out that Japan has developed competi ve

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[15]The four nonderived technologies are all in avionics: the phased array radar, the in ial reference system, the integrated electronic warfare system, and the mission computer. The comp ite wing is considered derived.

[16]"Bei ni 'Dokuji Gijutsu' Nintei Yokyu" (Demand to U.S. for "Independent Technol y" Designation), *Nihon Keizai Shimbun*, February 23, 1992, p. 1.

[17]Two representative pieces from that period are "Nihon no yui gijutsu, Beikoku no yui giju ," *The 21*, July 1989, pp. 28-29, and the occasional "Militeku" (Militech) series that ran in the *A hi Shimbun* from January 30, 1989 to March 4, 1989.

se will be able to capitalize on it—in military as well as commercial t development—is still an open question.

nally, there is also considerable disagreement about the value of Japanese logy developed for the program that U.S. industry will have access to as flowback or through licensing). Observers disagree on the quality of s phased array radar technology. While General Dynamics is reported to ound the flowback of composite wing technology from Mitsubishi to be with the sale of the fighter division to Lockheed—which has been l as superior to General Dynamics in composites technology—the te value of technology transfer in this area is uncertain. It is safe to say e value of the technology flow to the United States is nowhere near the hat has flowed to Japan through this program.

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Chinworth, op. cit., p. 155. He also remarks on the irony of the pains taken by the United States l transferring design technology during the F-15 program, only to transfer F-16 design gy to the same companies a few years later.

# U.S.-Japan Technology Linkages In Aeroengines [1]

Because jet propulsion is the key enabling technology underlying commercial and military aviation as we know it today, the engine industry plays a special role in the aircraft supplier base. U.S.-Japan technology linkages in the engine business are extensive and long-standing, and they cover a range of mechanisms. The global context of growing international alliances in the commercial and military jet engine businesses is also important. The experiences of the two American engine makers—General Electric and Pratt & Whitney—have been somewhat different.

## GE AIRCRAFT ENGINES

As a corporation, General Electric has a 90-year history of involvement with Japan. GE Aircraft Engines has been involved with Japan for more than 40 years (see Figure C-1). GE was involved with the first Japanese postwar military aircraft program starting in 1953 with the J47 engine for the Japanese version of the F-86 fighter. Over the next several decades, GE's J79 engine was chosen to power the Japanese versions of the F-104 and F-4. GE's relationships with Japan during this period involved sending kits to Ishikawajima-Harima Heavy Industries (IHI) for assembly and testing, with some components manu-

[1]Appendix C, like Appendix B, relies on the insights and interpretations of individual experts.

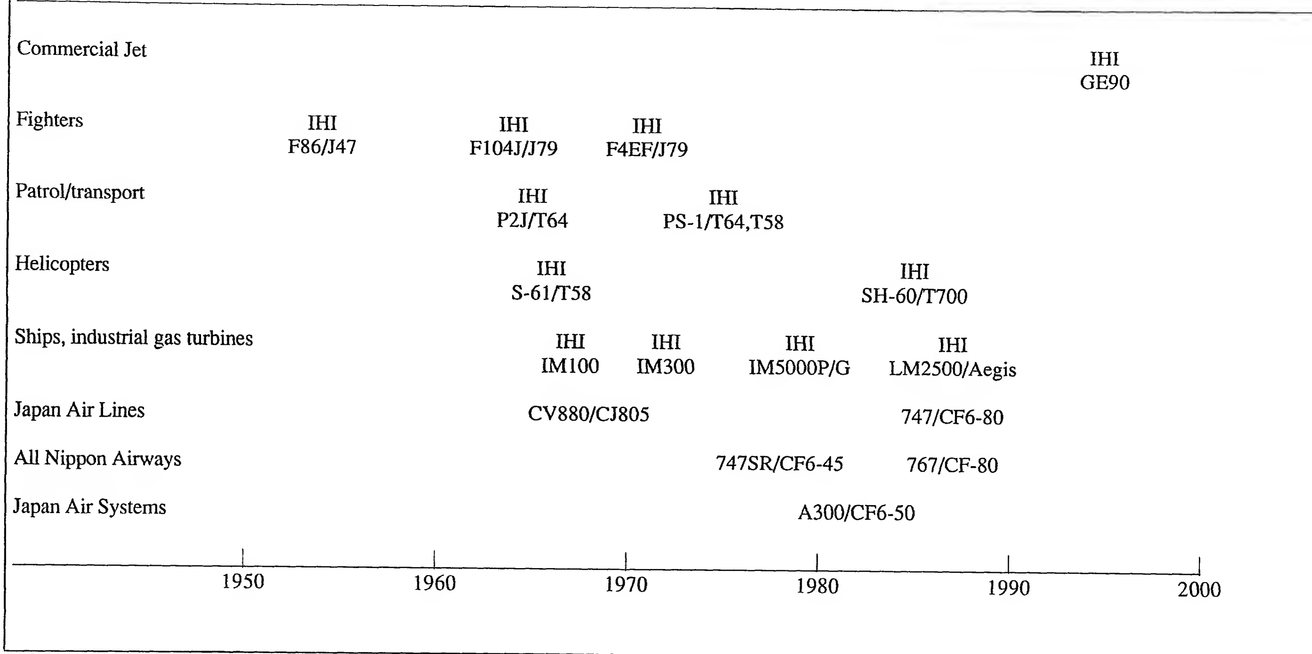
ntree to the Japanese Marine Self Defense Force (MSDF), helping it to
nentally displace Rolls Royce over the years.

s for activities in commercial jet engines, it is important to remember that d not emerge as a true force in the commercial business until the 1970s. first sales to Japan were to Japan Air Lines (JAL) in the mid-1960s, with 805 engine on the Convair 880. This engine was a derivative of the J79, number of in-service problems, and did not live up to its technical expec-s. At that point, GE exited the commercial market for a time, reentering 1 with the next generation of high-bypass technology with the CF6-6 and 0 engines for the DC10-10 and the DC10-30. This was followed by the uction of the CF6-50 engine on the 747 and the Airbus A300 in 1973. GE d several lessons that it put to work over the next several decades. As a of the CJ805 experience, GE built an excellent customer support organi-. Specific to Japan, GE learned that it is important to completely fulfill pectations of Japanese customers. GE did not make another commercial Japan until it reentered the commercial engine business in the late 1970s id not make a sale to JAL until the mid-1980s, when JAL selected the 0C2 for their 747-400s.

he opportunity to reenter Japan came when All Nippon Airways (ANA) d to upgrade and expand its fleet with the latest generation of wide-body ft. The initial opportunity with ANA led to a tremendous fleet of follow-es for 747s, 767s, and A320s. Japan Air Systems is also a major customer igure C-2). The big competitive issue today involves engine selection for 7s that JAL has already ordered. As the Japanese airlines have expanded fleets to accommodate more traffic growth, GE's market share has in-d. This has recently been augmented by the sale of CFM56-powered Air-rcraft in Japan. One interesting characteristic of the Japanese airlines is ey generally do not want to be the first to buy a major new aircraft or e. They desire the company of at least one other major airline to ensure ne needed support will be available if there is a problem. The manufac-s product support infrastructure is a major consideration in the selection engine.

E has focused its engine collaboration in Japan with IHI. The major orative programs relevant to this study are the GE90 and the F110 engine e FS-X. In addition to GE, IHI collaborates with Pratt & Whitney, Rolls , and others. This contrasts to GE's European partner, France's Snecma, has limited itself to GE. GE does not consider this a problem, because as not involved itself in technical development programs for competitive es, even though its involvement with programs such as the PW4000 or the Royce Trent may be large in terms of manufacturing work share. Further, collaboration with IHI in developing a commercial engine is fairly recent,

**FIGURE C-1** GE Aircraft Engines Relationships




SOURCE: GE Aircraft Engines.

elf, and GE has not felt compelled to seek one out.

## GE90

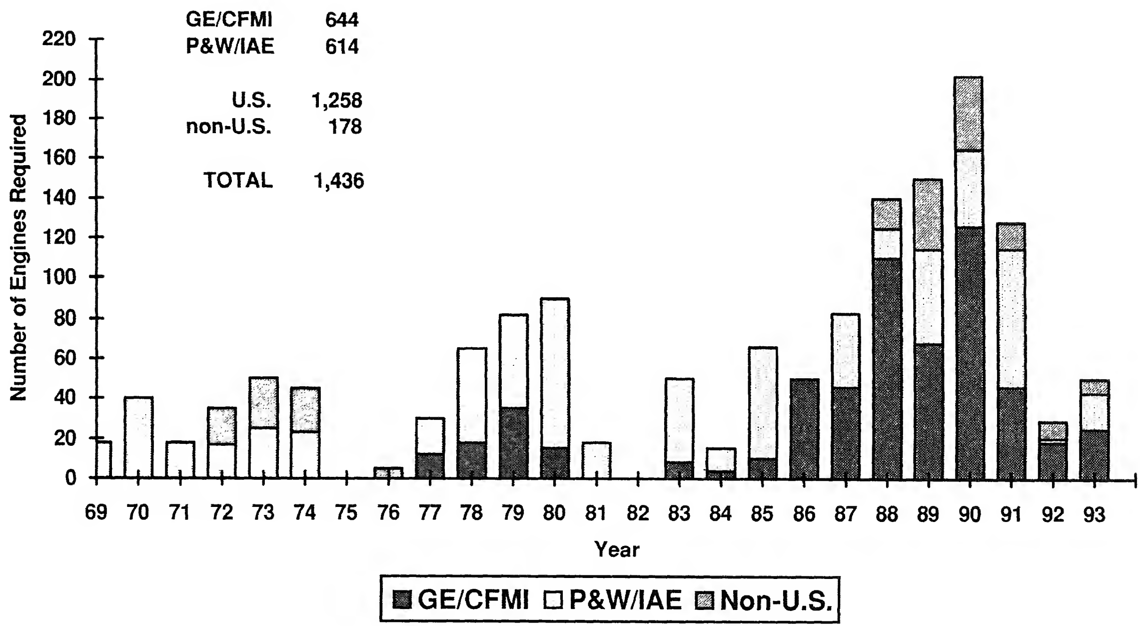
GE90 is the first of what GE hopes will be a new family of large en-
power the next generation of commercial transports. In the late 1980s, mined that the derivative path of the CF6 family had served its pur- decided on developing a new family of engines based on proven tech- his program was centered around the thrust requirements of Boeing's ly of aircraft. The major question was how the program would be l. In order to spread risk, obtain maximum leverage of development , and gain global market opportunities, it was decided that the pro- uld be structured around GE's existing international relationships. the French engine maker that is GE's partner in the CFM Interna- nt venture, is the anchor in Europe, with a 25 percent share of the pro- also made sense to include Italy's Fiat because of its long-standing ip with GE and expertise in several specific engine components. of the long, ongoing relationship with IHI, GE decided to approach it ticipation in the new program. IHI holds an 8 percent share in the the same as Fiat. Participation in developing future derivatives is an ty available to the partners.

o this point, GE's colloboration with IHI had not extended beyond uring. With the GE90, each partner is responsible for designing and g its specific part of the engine. Snecma has designed and will build ressor. IHI is responsible for several stages of turbine disks for the ure turbine, the blades in those disks, and the long shaft that goes he low-pressure turbine and the fan. IHI's interests and the ultimate f its work share are close to what GE envisioned when approaching outset.

ldition to design and development responsibility, program participa- ires partners to make considerable capital investments in testing and uring infrastructure. Because of the size and airflow of the GE90, test cells are required. IHI has proceeded to make the necessary in- to build a test cell (Snecma has also built a GE90 test cell, while GE built two). In addition, substantial tooling investments were also nec- accommodate parts with the large diameter of the GE90. Partners pared to make these investments because of the future potential of the

partnership extends for the life of the program. All commitments are in dollars. Typically, in a program relationship of this type, partners ey in one of two ways. First, they may be reimbursed for their work

## Annual Volume by Engine Manufacturer
## Engine Orders



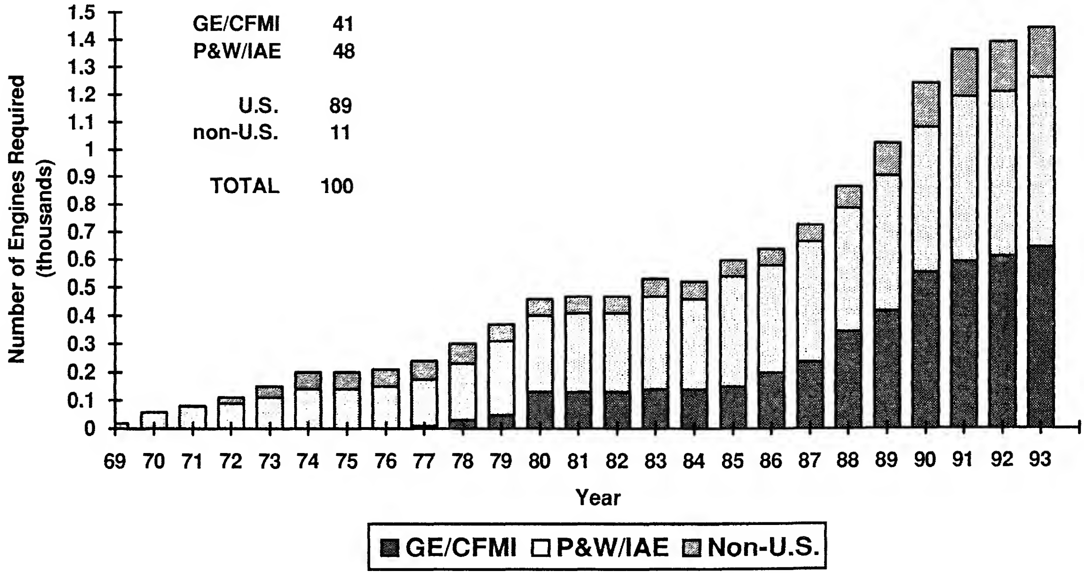



FIGURE C-2 Japan: engine orders. SOURCE: GE Aircraft Engines.

share.

In the actual agreement, various protocols and rules set out partner responsibilities fairly specifically. For example, if the Federal Aviation Administration needs to extend flight tests or if there are other unanticipated costs that extend to the entire engine, the partners share these costs. If, however, there is a problem with a specific part of the engine, fixing that problem is the responsibility of the partner that designed and built the part. Generally, international partners make an up-front investment at the outset of the program in recognition of the unique contributions of the principal partner in the areas of marketing and support infrastructure, and of its established reputation in the industry. Finally, although the partners may have no formal role in marketing the engine, they do participate in support of sales campaigns in certain cases.

The GE90 is currently undergoing testing and certification; it is scheduled to enter service in 1995. Although it is not possible to assess the bottom-line impacts on the participants, GE is pleased with the partnership and with IHI's contribution to this point. The disks and turbine blades were impeccably designed and manufactured the first time around. GE has also learned some useful lessons from IHI. For example, IHI developed the casting method for the high aspect ratio turbine blades. GE gave IHI the aerodynamic coordinates on tape, which IHI quickly translated into tooling. At that point, the attachment of the blade to the disk or the tip shroud had not yet been designed. IHI said that since the major technical challenge would be to develop a good casting of the airfoil, knowing the specifics of the attachment and tip shroud was unnecessary. IHI delivered the casting in six weeks, with lumps of metal at each end that could be machined later. This fast prototyping provided insight to a "best practice" that has broad application. Under GE's old process, which had involved special casting drawings and required numerous signatures and procedures to approve changes or finalize the design, it would take a year to build tooling and prove out the casting process. In examining its process, GE realized that it was encumbered by procedures necessary for military engines, carried over to the commercial side. Making use of best practices, GE is reviewing and changing its processes for commercial engines to reduce the product development cycle time.

The origin of IHI's blade casting capability is worth noting. IHI had been developing structural and airfoil casting capability throughout its domestic network. A major advancement was realized in 1978 when as part of the F101 license agreement IHI acquired the right to cast the low-pressure turbine airfoils of equiaxed material. At that time, it was refused rights to the directionally solidified high-pressure turbine foils. In 1983 IHI acquired the rights to directionally solidified processes and materials. With this and the aid of the Technology Research and Development Institute (TRDI), IHI continued casting d

monocrystal process using procured material. Although the most ad-
onocrystal process is not used for the GE90 blades, they are nonethe-
challenging to make, and GE rates IHI's process very highly.

## F110

a fierce competition, GE's F110 engine was selected over Pratt & s F100 as the engine for the FS-X. From the Japanese standpoint, the r considerations were probably the higher gross weight of the FS-X nd the thrust growth potential of the F110 engine.

lopment work is currently going forward between GE and IHI. This ntegrating the engine with the FS-X airframe and developing the in- features. Since the engine will not be markedly different from the d on the F-16 fighter, the development phase is a relatively simple nd will not involve a great deal of technology transfer or new technol- opment. The Japanese aim to build as much of the engine as possible outset, but U.S.-Japan negotiations on an FS-X production memoran- nderstanding (MOU) have not been completed as of this writing. In f the F100, Japanese production under license has eventually reached percent.[2]

## Other Collaboration

nd IHI collaborate in several other areas. The HYPR program is cov- w. In addition, in July 1992 the two companies signed a broad MOU selected technologies jointly. GE initiated the MOU because it real- opportunities to learn from IHI will increasingly arise as IHI develops chnologies through independent efforts and as part of Japanese gov- sponsored programs. GE would provide some of its know-how in ex- The MOU provides an umbrella structure for identifying and pursuing pportunities. As of this writing these opportunities are under discus- no specific initiatives have been formalized.

formal technology transfer procedures are followed on each specific undertaken with IHI (or any other partner). First, the business unit

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y 1993, the Japanese press reported that GE was willing to allow IHI to produce "most" of der license from the outset. The report also stated that GE's relatively open stance could tions for other aspects of the program. Since the two countries have agreed on a 40 percent for U.S. companies and it was assumed that the United States would begin by producing a f the engine, an unexpectedly large Japanese share of the engine means that the U.S. share the aircraft would have to be increased accordingly. "Nihon ni Gijutsu Kyokyu--Bei GE, Raisensu" (Technology to Be Provided to Japan—U.S. GE Will License to IHI), *Nihon bun*, May 20, 1993, pp. 1, 11.

license, and then to the Department of Defense (DOD) and the Department of Commerce as necessary. GE's licensed production contracts with IHI—going back to the J47—include flowback provisions in which GE will obtain improvements that IHI makes in its technology. In addition, GE rotates engineers through Japan and IHI in order to keep abreast of the Japanese partner's manufacturing and technological capabilities, as well as to manage collaborative programs. Where possible, GE uses engineers with Japanese language ability and provides language training for its employees stationed in Japan.

In addition to the technology development program, the two companies collaborate extensively on derivative engines for marine and industrial use. The LM2500, a derivative of the CF6, is used in Aegis-class cruisers and frigates, including the MSDF fleet. The engine is also used in electrical cogeneration. The GE division that makes power systems, of course, has its own extensive business and collaborative interests in Japan. However, conventional power systems take up to seven years to plan and complete. A cogeneration package using an aero-derivative engine can be put on line in about a year. IHI helps to manufacture and market these systems. For the LM2500 and the more recent LM5000—a derivative of the CF6-50—IHI has played a significant role in developing the product and aggressively marketing cogeneration systems.

## PRATT & WHITNEY

Pratt & Whitney's (P&W) technology linkages with Japan are also extensive, and have included a slightly wider range of mechanisms and partners than GE's. P&W established a relationship with MHI in the 1930s that was interrupted by World War II, and has also linked with IHI and KHI. P&W's motivations for establishing technology linkages with Japan are similar to GE's—risk-sharing Japanese partners provide leverage for development funds; market access; a commitment to high quality, low-cost, and timely delivery; and increasingly new technology. Thus far, the cost and risk-sharing benefits have been most prominent. Although P&W closely monitors the technological capabilities of its Japanese partners—particularly in the manufacturing and materials areas—it has not incorporated Japanese developments to the extent that GE appears to be.

### Manufacturing Alliances

Pratt & Whitney has undertaken a number of collaborative manufacturing ventures with Japanese partners over the years. These programs have covered both commercial and military engines, and have involved licensed production

he first two complete engines—to be used by IHI in calibrating its quipment—were delivered in May 1979, and eight knock-down kits vered beginning in August 1980. In September 1981, IHI produced the ne under license, and 290 F100-IHI-100 engines were made under this it through April 1990. Some of the materials and the electronic engine were held back by DOD, but IHI manufactures about 75 percent of the dollar value.

the last several years, the F100 relationship has evolved further, as porates improvements that P&W developed for the U.S. version of the om April 1990 until September 1993, IHI produced under license the -100BJ—which incorporated an increased life core—at the rate of two per month. In September 1993, IHI began production of the IDEEC -220E engine at the rate of two per month, and it was scheduled to rofitting prior engines with 220E hardware at the rate of three per March 1994. The major advance in the 220E is digital electronic con- ll, IHI is scheduled to produce 472 F100s of all versions under the ontract.

/ launched an earlier and less extensive military licensed production it in 1971 with MHI covering the JT8D-9 engine. MHI produced about engines over 10 years for Japan's C-1 military transport. In 1984, ame a 2.8 percent risk-sharing partner in the manufacture of a deriva- luct, the 20,000-pound JT8D-200, which powers the McDonnell MD-80 series. Under this agreement, MHI is responsible for the manu- f various turbine blades, disks, and cases. In joining an existing pro- HI had no development role.

/ has two Japanese partners in the PW4000 program, a large engine ers some versions of the Boeing 767 and whose derivatives will be n some versions of the Boeing 777. The engine was originally devel- he late 1970s. Kawasaki became a 1 percent risk-sharing partner in d it has continued at that level since then. It is responsible for manu- several airseals, a shaft coupling, and a pump. MHI signed on as a 1 isk-sharing partner in the PW4000 program in 1989, and since then its ion grew to 5 percent in 1991 and 10 percent in 1993. MHI is respon- manufacturing various turbine blades and vanes, turbine and compres- , active clearance control components, and combustion chambers. g participation at such a low level reflected P&W's desire to "test the nd establish a working relationship with its partners before investing a l in the alliance. The increase in MHI's share since 1989 has come a result of mutual satisfaction with the relationship and desire to ex-

for the JT8D (low-pressure turbine and low-pressure compressor disks) and JT9D (low-pressure turbine blades).

IHI now manufactures all of Pratt & Whitney's long shafts. Utilizin and improving upon the process transferred in connection with the F100 prog am, IHI has become a world-class center for the production of long shafts of ore than 8 feet. As mentioned earlier, IHI will be manufacturing the long sha for the GE90, and it manufactures all of Rolls Royce's shafts as well. This spe ali-zation is not uncommon in the engine business—Fiat dominates the man ac-ture of gear boxes, and Volvo is strong in casings. Although IHI's domin nce in shafts raises issues of dependence and possible supply disruption, the er ine "primes" manage this dependence by maintaining some capability of their vn. It is also widely believed that any attempt by a supplier of critical engine m-ponents to use delay or denial to extract money or technology from the pr nes would spell death for that supplier in the international market. The foc sed manufacturing approach does carry significant benefits in terms of cost nd quality.

## INTERNATIONAL AERO ENGINES (IAE)

International Aero Engines is a global consortium that developed an is currently manufacturing and marketing the V2500 engine. It consists of Pra & Whitney, Rolls Royce, Fiat, MTU, and Japan Aero Engines Company (JAE ).[3] Although IAE currently has just one product—the V2500 engine—the alli ce includes a 30-year commitment to produce engines in the 18,000 to 30,( 0-pound range and has provisions for studies of engines up to 35,000 pound of thrust. As of this writing, 104 V2500s have been delivered, the order bacl og stands at 284, and airlines hold options on 302 more.

The partner companies in IAE were responsible for developing as wel as building their share of the engine. The lead partners—Pratt & Whitney nd Rolls Royce—both hold 30 percent shares in the program. P&W is respons le for the high-pressure turbine and the combustion system, whereas Rolls Rc ce designed and manufactures the high-pressure compressor and the lubrica on system. In addition to the program shares, P&W holds a separate contract or overall engine management and manages the electronic engine control. R ls Royce manages the design and manufacture of the nacelle and is also respo i-

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[3]Background on the formation of IAE is contained in David C. Mowery, *Alliance Politics nd Economics: Multinational Joint Ventures in Commercial Aircraft* (Cambridge, Mass.: Balli er Publishing Company, 1987) and Richard J. Samuels, *Rich Nation, Strong Army: National Secu y, Ideology, and the Transformation of Japan* (Ithaca, N.Y.: Cornell University Press, forthcor ng 1994).

)0 responsibilities are similar to their participation in PW2037 devel-
d manufacturing. JAEC holds 23 percent of IAE, and is itself a joint IHI (with 60 percent of JAEC), Kawasaki (25 percent), and MHI (15 JAEC is responsible for the fan and the low-pressure compressor. JAEC has representatives in the marketing department of IAE, P&W Royce are fundamentally responsible for marketing. Technical sup- airlines is accomplished largely through P&W's existing system.

nd the V2500 program were carefully structured to minimize tech- nsfer between the partners. This was partly motivated by DOD ıbout transferring P&W's high-pressure turbine technologies, but it ts the competitive concerns of the partners.[4] Like the CFM56, the l other collaboratively designed engine programs, the V2500 utilizes design in which a complete engine can be assembled and tested great deal of knowledge exchange concerning the individual pieces. its of risk and cost sharing, specialized manufacturing, and market ıust be balanced against the built-in overhead cost and time disadvan- volving so many companies, as well as the extra time and care re- negotiate interface designs that limit the flow of technology. Still, hitney will benefit to the extent that there are generic rules and prac- g from the V2500 experience that can be applied to managing future ve programs.

the non-U.S. members of IAE received support from their govern- their participation. Rolls Royce received a $150 million no-interest the British government, slightly less than half of the cost of partici- t it estimated at the outset, to be repaid through a royalty on each C has received annual payments of $20 million to $25 million from ry of International Trade and Industry (MITI) since the start of the JR710 program in the early 1970s, and this support has continued 2500 development, covering roughly 75 percent of JAEC's develop- , 66 percent of testing costs, and 50 percent of the production tooling curring startup costs.[6] Repayment with interest of these success-con- ɔans is slated to commence when the program breaks even. Exact government support extended to MTU and Fiat are more difficult to

'2500 faces tough competition from the CFM International CFM56, s to be gaining greater market acceptance over time. Although the E agreement requires the partners to work together on engines in the

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y, ibid., p. 94.
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in a way that the partnership can be expanded if desirable from a business standpoint, but does not constrain the partners as they pursue their individual strategies.

## HYPR AND OTHER JAPANESE GOVERNMENT PROGRAMS

The Japanese Supersonic/Hypersonic Propulsion Technology Program (JSPTP or HYPR), was launched by MITI in 1989, with funding originally set at \$200 million over eight years. It is now expected that the program will be stretched to ten years. The ultimate goal of the program is the development of a scale prototype turbo-ramjet, Mach 5 methane-fueled engine. The program is administered by MITI through its Agency of Industrial Science and Technology and the quasi-governmental New Energy Development Organization. The specification of a Mach 5 methane engine was partially determined by Japanese bureaucratic politics. MITI was not able to obtain Ministry of Finance approval to fund a supersonic engine program, but it could utilize funds earmarked for energy conservation R&D if the targeted development utilized an alternative fuel such as methane.

The Japanese partners—IHI, Kawasaki, and MHI—receive 75 percent of the funding and take the lead on technology development and design. HYPR is significant in that it is the first of Japan's national R&D projects to contemplate international participation from the outset as an integral feature of the program. The foreign participants—who receive 25 percent of the funding—are Pratt & Whitney, GE, Rolls Royce, and Snecma. The formal agreement between MITI and the foreign engine companies was signed in early 1991. The process of negotiating the participation of the foreign engine companies was somewhat long and complex. The major stumbling block arose surrounding the treatment of intellectual property generated in the project. The standard treatment of intellectual property in Japan's government-sponsored R&D is that the government owns 50 percent and exercises effective control over the disposition of intellectual property rights (IPR). The four foreign companies, wanting to avoid possible future restrictions on IPR, joined together to negotiate with MITI as a united front. This process led to an agreement and a change in Japan's laws governing the administration of government-sponsored R&D. Purely domestic projects follow the same rules as always, but IPR is treated differently in designated international projects such as HYPR as a result of the change. The foreground results and patents of technology developed in the program are owned jointly by the foreign and Japanese companies that developed them. Individual companies can use their own results without restriction, but they must negotiate with MITI over fees if an outward license is contemplated. Access to patents

anese companies are taking the lead on various program elements. t, the participating U.S. companies report satisfaction with the pro- work and the flow of information. From the point of view of GE Whitney, the main motivation for participating is that taking a ole in the Japanese program is preferable to a major super- onic engine program going forward without U.S. involvement. By ;, GE and Pratt & Whitney gain insights into the basic design d capabilities of the Japanese members of HYPR. Besides, because ding, participation is not costly for the foreign firms. It was neces- wo companies to touch bases with the Departments of Defense and t the outset, and to convince them of the rationale. Eventually, the ment was persuaded that "riding in front of the stampede" made han sitting on the sidelines. U.S. engine makers believe that as a ıus for flights of the next-generation supersonic transport, Japan ly be involved in its development. GE and Pratt & Whitney are g on research funded by the National Aeronautics and Space on (NASA) on high-speed civil transport propulsion targeting an Mach 2 to 2.5 range. The NASA program involves a much higher l than Japanese government support of HYPR. The U.S. engine ot transferring technology from this work to the Japanese.

ic interaction between foreign and Japanese companies in HYPR is in design review and analysis in designated program areas. GE or tney will look at the designs of, respectively, IHI and KHI, critique d coach them on possible new directions. Each of the foreign com- ns five to ten engineers to the project. On the Japanese side, the gement headquarters has a staff of 11, but a minimum of 500 engi- three companies charge at least part-time to the program.[8]

e program is currently in its fourth year and will probably run for acts and implications cannot be assessed precisely. The eventual depend a great deal on the timing and mechanism for developing or the next-generation supersonic transport. While foreign partici- s the major international players to gain knowledge about Japan's e Japanese participants gain design insights from foreign coaching. tional participation in HYPR has itself served to give credibility to orts to play a significant role in international advanced engine pro- other Japanese government efforts to organize international R&D 1.

onal Group to Build Combined Cycle Hypersonic Engine," *Aviation Week & Space* gust 17, 1992, p. 50.

funding pool. The program, which began in 1989 and is scheduled to run through 1996, is organized into two parts. One branch includes six government laboratories, while the other—which is known as the Research and Development Institute of Metals and Composites for Future Industries (RIMCOF) is composed of nine companies and four universities. RIMCOF itself was launched in 1981, and completed two MITI-sponsored R&D programs on composites and crystalline alloys from 1981 to 1988. Toray was the main industrial participant and beneficiary of the composites project.[9] In the current project, the focus is on intermetallic compounds, heat-resistant fibers, composites, and reinforced intermetallic composites that could be utilized in supersonic or hypersonic engines.

Japanese government and industry have been working together on subsonic engine technologies as well. The Frontier Aircraft Basic Research Center Co., Ltd. (FARC) was established by the Key Technology Center in 1986 to develop the technology required for an advanced turboprop engine. FARC, which operated through the beginning of 1993, included 34 companies in all. In addition to the major engine and airframe "heavies," auto, materials, and machinery manufacturers are also involved.[10]

In addition to these ongoing programs, the Japanese government—mainly MITI and TRDI—are conducting a number of feasibility studies aimed at significantly upgrading Japan's engine testing facilities over the next decade. The most important of these is an altitude test facility to be built in Hokkaido at a projected total cost of $140 million.

## JAPANESE CAPABILITIES IN THE AERO ENGINE BUSINESS

Japanese aircraft engine makers have effectively leveraged private and public resources in international alliances and public R&D projects to improve and deepen their technological and manufacturing capabilities. Individually or as a group, Japanese companies are well positioned to continue to participate in international engine development programs at increased levels of technical and manufacturing responsibility. Japan's government technology programs and corporate strategies are aimed at gaining world leadership in some aspects of propulsion materials and other critical technologies.

As in the aircraft systems segment, barriers to Japan's entry as a major player at the level of today's international engine "big three" remain. To begin

[9] Michael Dornheim, "MITI Pursues Improved High Temperature Materials," *Aviation Week and Space Technology*, August 17, 1992, p. 54.

[10] See Samuels, op. cit., for a detailed description of FARC.

ıd market credibility, or an acquisition. In the case of the American DOD has guarded hot section technologies over the years. While it difficult to conceive of a circumstance in which DOD would allow of these technologies through license or acquisition, the U.S. policy hanging.

; current technological capabilities are quite impressive in several gine manufacturing and technolgy. The Japanese can manufacture of a modern engine and can design key pieces. IHI in particular is ; in application of technology once it has mastered the basic concept. cturing practices—including total preventive maintenance—are very ; are its laser drilling capabilities. The proof of this is in the prodıd the other Japanese companies hold tolerances very well.

panese engine makers do have significant weaknesses. Across the 'apanese companies are weak in software and lack sophistication in cal tools necessary to do world-class design. For example, when sign a compressor blade, the Japanese are capable of very competent design. However, it takes time for them to experiment and trade off iical and aerodynamic features. The U.S. engine companies have rograms that can optimize both mechanical and aerodynamic charn designing blades.

panese are aware of their weaknesses in software and systems intehodology, and are asking more often for access to analytical tools in ational alliances. These are the technological "crown jewels" that gine companies guard fiercely. Even if they were willing to transfer of the the management methodologies are best learned by actually mplete engine program. In the case of some design tools, such as e Japanese may possess the software, but they have only a thin al data base to plug into it to gain optimum value from the software. Japanese engine makers have relatively high unit manufacturing verhead, disadvantages that are currently being exacerbated by the ppreciation.

ınd the JDA have supported the Japanese aircraft and engine indushe aim of helping them to become world leaders. There may be a ount of frustration that industry is not further along, given the amount of public funds spent on various aspects of aircraft develere has been a recent willingness to allow or even encourage non'apanese players to test the waters. In the engine world, these are the companies—Toyota, Nissan, and Honda.

: these weaknesses, the Japanese have developed a significant manund technological base in the engine business. Government and innue to team in the development of advanced technologies—in mate-

increased over the past decade, and Japanese government-sponsored prog ams are aimed at developing a technology base to further expand this role. s in airframes, new directions in international collaboration—either with the us-sians or other new partners, or through selective utilization of experts idl by worldwide defense cuts—are feasible strategies. In parallel with the airf me business, current global restructuring is challenging the Japanese as it is al-lenging other players. However, the rewards are likely to go to companie and nations committed for the long haul, as the Japanese clearly are.

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